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PROPOSED CRITERIA FOR WATER QUALITY

Volume I

OCTOBER 1973

U.S. ENVIRONMENTAL PROTECTION AGENCY
Washington, D.C. 20460

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FOREWORD

The Federal Water Pollution Control Act Amendments require the Administrator of the U.S. Environmental Protection Agency to publish both criteria for water quality and information for the restoration and maintenance of aquatic integrity, and the measurement and classification of water [Section 304a(a)1 and 2, P.L. 92-500].

Volume I of this two volume series contains the criteria for water quality for the protection of human health and for the protection and propagation of desirable species of aquatic biota. Volume II of the series contains information on the maintenance and restoration, measurement, and the classification of waters. Also those pollutents suitable for maximum daily load calculations are identified.

Both Volumes I and II are published as proposed documents with a 180 day period provided for public comment.

Russell E. Train

Russell E. Train
Administrator

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This water quality criteria document is Volume I of a two-volume publication. The criteria are arranged alphabetically by water use, with the limits for each pollutant followed immediately by the supporting scientific rationale. It contains information on factors necessary for the restoration and maintenance of the integrity of the Nation's water; the protection of fish, wildlife and human health; the identification of pollutants; and the measurement and classification of water quality.

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Environmental Protection Agency

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Volume I

Proposed
Criteria for Water Quality
The Environmental Protection Agency

I. LEGISLATIVE BASIS

Section 304(a)(1) of the "Federal Water Pollution Control Act Amendments of 1972", hereinafter referred to as the "Act", provides that the Administrator (EPA) shall within one year of enactment (by Oct. 18, 1973) publish, and revise from time to time thereafter, water quality criteria. The criteria shall reflect the latest scientific knowledge on: A) all identifiable effects of pollutants on human health, fish and aquatic life, plant life, wildlife, shorelines, and recreation; B) concentration and dispersal of pollutants; and C) effects of pollutants on biological community diversity, productivity and stability, including factors affecting rates of eutrophication and sedimentation.

The National Water Quality Standards Program was initiated with the passage of the Water Quality Act of 1965, Sec 10(c). The Water Quality Standards are comprised of use designations for each water body or portion thereof, water quality criteria to support the use designations, and implementation plans for scheduling the construction of the necessary treatment facilities. The designations by water uses are protection and propagation of fish and wildlife (fresh water and marine), makeup water for public water supplies, recreational, agricultural, and industrial. The water quality standards prior to the Act were applicable to only interstate waters and their tributaries. The Act provides for this coverage to be extended to intrastate streams and the State standards have since been, or are in the process of being revised accordingly.

The objective of the Act is to restore and maintain the chemical, physical and biological integrity of the Nation's waters. The National goal, Sec 101(a)(1), is to eliminate the discharge of pollutants into navigable waters by 1985, with an interim goal, Sec 101(a)(2), being to attain by July 1983, water quality which provides for the protection and propagation of fish, shellfish and wildlife and for recreation in and on the Nation's water.

In implementing the Act EPA has, as part of the National Water Quality Standards Program, instituted a stream use classification policy that provides for the protection of _all_ waters to sustain recreational uses in and/or on the water, and for the preservation and propagation of desirable species of aquatic biota. Such levels of protection then make all waters suitable for other uses such as public water supply, agriculture and irrigation.

II. INTRODUCTION

This water quality criteria document is Volume I of a two-volume publication. The criteria are arranged alphabetically by water use, with the limits for each pollutant followed immediately by the supporting scientific rationale. The numerical criteria are also synopsized in a tabular summary (Appendix B) for ready comparison. Volume II, under separate cover, entitled "Water Quality Information". fulfills the requirements of Sec 304(a)(2) of the Act. It contains information on factors necessary for the restoration and maintenance of the integrity of the Nation's water; the protection of fish, wildlife and human health; the identification of pollutants; and the → p 12

Cont'd fr p. 11

measurement and classification of water quality. Specifically, Volume II provides information on the sources of polluting constituents (manmade and natural), mean levels in major river basins, techniques for biological and physical measurements, methodology for bioassays, the overall classification of water quality, and the types of pollutants suitable for maximum daily load measurements.

Water quality criteria as compiled in this document (Volume I) are defined as the acceptable limits of constituents in receiving waters based upon an evaluation of the latest scientific information by the Environmental Protection Agency. They are to form the datum for the Agency's 1983 interim goal of improving the Nation's waters to a quality that provides for the protection and propagation of fish and wildlife, and for the health of humans in their pursuit of recreation in and on these waters. Almost all of the criteria are taken from the recommendations of the National Academy of Science's report on Water Quality Criteria (in press) developed under contract to the Environmental Protection Agency. For a more thorough treatment of the broader aspects of water quality the user is referred to that report.

The criteria are based upon toxicity studies and other field and laboratory tests which assess the effects of pollutants on agricultural crops, domestic livestock, aquatic life, wildlife and man. The acceptable limits specified in the criteria for substances which exhibit toxic effects were derived by the application of scientific judgement to lethal dose or lethal concentration data in a manner that provides a margin of safety to test organisms. For those substances whose effects are more aptly described as undesirable such as impairing aquatic habitats, causing taste and odor problems in water supplies, or reducing the aesthetic or recreational quality of a water body, limits which minimize these effects were established on the basis of field and laboratory investigations. Acceptable levels of toxic materials for which specific numerical maximum acceptable concentrations are not prescribed are determined by applying an application factor to locally derived LC_{50} data; (i.e., to the concentration of the constituent in the water in question which causes death within 96 hours to 50 percent of a test group of the most sensitive important species in the locality under consideration). By basing criteria on effects on the most sensitive important species, a desirable degree of regional and local variation is introduced, allowing water quality standards to depend on local conditions. The criteria will be revised from time to time to reflect new scientific knowledge, as required by the Act.

An "important species" in the criteria is defined as an organism that is: a) commercially or recreationally valuable; b) **is rare or endangered; c) affects the well-being of** some species within a) and b); or d) is critical to the structure and function of the ecological system. A "rare or endangered" species is any species so officially designated by the U.S. Fish and Wildlife Service.

The NAS Report recommendations provided several choices of levels of protection for such constituents as pH, dissolved oxygen, settleable and suspended solids. In these cases the recommendations that provided a level of protection consistent with the objective of the Act, but not necessarily the highest levels of protection **offered were** selected by EPA as the limits or ranges of limits that are acceptable to this Agency. By so doing the acceptability datum can be established at a level that should provide the basis for an improvement in the quality of most waters to meet the 1983 goal, while not requiring the economic burden that would result from requiring "nearly maximum levels of protection." Water quality standards based upon these criteria are to be developed on a local basis to minimize impairment.

While it is recognized that the synergistic effects of certain combinations of pollutants portend greater risks than the simple additive combination of the effects of each pollutant, most of the criteria are not based upon synergistic studies. The EPA Office of Research and Development is presently engaged in programs to expand our knowledge of synergistic effects. When such information becomes available revisions to these criteria will be made. Users should therefore use judgement and apply additional safety factors in cases where there is a known potential for some specific pollutants in a water body to have a synergistic effect.

In most cases the criteria for a given category of water, e.g., irrigation water, livestock water, freshwater aquatic life are based upon studies of the effects on the types of organisms (plants, livestock, aquatic organisms). In some instances however, where some constituents such as molybdenum in irrigation waters, mercury in fish, etc. are biologically magnified to levels that would be dangerous to higher order animals or man, the acceptable limits are prescribed to provide for the protection of these consumers.

III. MAJOR USES OF THE CRITERIA

Water Quality Standards, Toxic and Pretreatment Standards, Water Quality Inventory (Monitoring), Toxic and Pretreatment Effluent Standards, National Pollutant Discharge Elimination System, and Ocean Discharge Criteria are the key control programs under the legislation for improving the quality of the Nation's waters and as such will probably be the major users of the criteria. Water quality criteria together with effluent limitations are the two scientific/technical undergirders of the entire national water quality improvement program and will provide the basis for the 1983 interim goal and the 1985 goal of no discharge. As such they are foundations of all water quality control programs of the Environmental Protection Agency.

The effluent limitations are based initially upon control technology in relation to such varying factors as application costs relative to benefits, equipment age, engineering, and non-water quality environmental impact. They are to be continually assessed to assure their non-interference with the attainment or maintenance of water quality, as specified by the ambient criteria. EPA Water Quality Criteria will be incorporated into revised State water quality standards under the direction of EPA Regions by means of policy guidelines developed by the EPA Office of Water Planning and Standards. Those guidelines have provisions for waters to be exempted from specific criteria on a case-by-case basis for specified periods when naturally occurring conditions exceed limits of the EPA criteria or other extenuating conditions prevail to warrant such exemptions.

Some of the pollutants for which criteria are established herein may be listed as toxic pollutants under subsection 307(a). In such cases the Agency will proceed under subsection 307(a) to examine the selected pollutants closely and rigorously, and will consider a broad range of data and factors which may not have been considered in developing the criteria set forth herein.

The criteria are based upon current knowledge of the effects on health and welfare of the presence of various pollutants in receiving waters. It must be emphasized, however, that many other factors must be considered in making decisions relative to establishing particular standards and control measures. Some of the more important considerations are:

> The nature of the environmental effect of the presence of pollutants in water (e.g., long or short term, temporary or permanent, localized or widespread, etc.).
>
> The economic and social impact of the standards and control measures and the impact of the environmental damage to be alleviated.
>
> The practicality and enforceability of the standards and control measures, including the availability of techniques and instrumentation for determining whether particular standards are being met.

Thus, this document provides availabile scientific information to the States for the purpose of carrying out the Federal Water Pollution Control Act.

IV. AGRICULTURAL CONSTITUENTS

A. General

Acceptability of water quality for general farmstead uses, including drinking, other household uses, and handling of produce and milk, is the same as that designated by Federal Drinking Water Standards. Also impurities that are offensive to sight, smell, and taste are not acceptable.

Rationale (General Agricultural Constituents):

Farmers and ranchers usually do not have access to large well-controlled water supplies of most municipalities. Therefore for their protection, water of a quality at least comparable to that intended for urban users is required. Water of such quality is necessary for drinking and other household uses, as well as for the handling of produce and milk (1).

B. Irrigation

1. Acidity, Alkalinity, pH

Because most of the effects of acidity and alkalinity in irrigation waters on soils and plant growth are indirect, no specific pH values can be prescribed which are acceptable for irrigation. However, waters with pH values from 4.5 to 9.0 are acceptable for irrigation purposes provided that care is taken to detect the development of harmful indirect effects.

Rationale (Acidity, Alkalinity, pH):

Since water itself is unbuffered and the soil is a buffered system (except for extremely sandy soils low in organic matter), the pH of the soil will not be significantly affected by the pH of irrigation water except in extreme circumstances (1).

2. Biochemical Oxygen Demand (BOD)

Because there is very little information regarding the effects of using irrigation waters with high BOD values on plant growth, it is not possible to prescribe any specific BOD limits.

Rationale (Biochemical Oxygen Demand):

The need for adequate oxygen in the soil for optimum plant growth is well recognized. Soil aeration and oxygen availability normally present no problem on well structured soils irrigated with high quality water. However, in poorly drained soils, oxygen may become limiting and irrigation with water having high BOD or COD (Chemical Oxygen Demand) could aggravate this condition by further depleting available oxygen. Infiltration into well drained soils can decrease the BOD of the irrigation water, but without seriously depleting the oxygen available for plant growth in the soil (1).

3. Inorganics (Ions and Free Elements/Compounds)

a. Aluminum

The maximum acceptable concentration of aluminum in water for continuous irrigation is 5.0 mg/l. The maximum acceptable concentration of aluminum in irrigation waters for fine textured neutral to alkaline soils for a period of not more than 20 years is 20.0 mg/l.

Rationale (Aluminum):

Aluminum exhibits significant toxicity in acid soils but at pH values from about 5.5 to 8.0, soils have great capacities to precipitate soluble aluminum and to eliminate its toxicity. Most irrigated soils are naturally alkaline and many are highly buffered with calcium carbonate. In these situations aluminum toxicity is effectively prevented. In spite of the potential toxicity of aluminum this is not the basis for the establishment of maximum concentrations in irrigation waters, because ground limestone can be added where needed to control aluminum solubility in soils. Nevertheless, two disadvantages remain. One is that salts that are the sources of soluble aluminum in water acidify the soil and contribute to the requirements for ground limestone to prevent the accumulation or development of soluble aluminum. This is a disadvantage only in acid soils. The other disadvantage is a greater fixation of phosphate fertilizer by freshly precipitated aluminum hydroxides (1).

b. Arsenic

The maximum acceptable concentration of arsenic in water for continuous irrigation on all soils is 0.10 mg/l. The maximum acceptable concentration of arsenic in irrigation waters for fine-textured neutral to alkaline soils for a period of not more than 20 years is 2.0 mg/l.

Rationale (Arsenic):

The most definitive work with arsenic toxicity in soils has been aimed at determining the amounts that can be added to various types of soils without reduction in yields of sensitive crops. On the basis of several experiments (2-4, 6-11) it has been shown that the amounts of total arsenic that will produce toxicity vary with soil texture and other factors that influence the adsorptive capacity. Assuming that the added arsenic is mixed with the surface 15 cm (6 in.) of soil and that it is in the arsenate form, the amounts that produce toxicity in sensitive plants vary from 112 kg/hectare (100 lbs/acre) for sandy soil to 337 kg/hectare (300 lbs/acre) for clay soils. For long periods of time involved, such as would be the case with accumulations from irrigation water, possible leaching in the soils (10) and reversion to less soluble and less toxic forms of arsenic (4) allow extensions of the amounts required for toxicity. The only effective management practice known for soils that have accumulated toxic levels of arsenic is to change to more tolerant crops. Toxicity studies (13) suggest that rice on flooded soils is extremely sensitive to small amounts of arsenic, and that the maximum acceptable limits given here are too high for this crop.

c. Beryllium

The maximum acceptable level of beryllium in water for continuous irrigation is 0.1 mg/l. The maximum acceptable concentration of beryllium in irrigation water for neutral to alkaline fine-textured soils for a period of not more than 20 years is 0.5 mg/l.

Rationale (Beryllium):

Some varieties of citrus seedlings show toxicities at 2.5 mg/l of beryllium whereas others show toxicity at 5 mg/l in nutrient solutions (12). Beryllium at 0.5 mg/l in nutrient solutions was reported to have reduced the growth of bush beans (14). Also, 2 mg/l or greater in nutrient solutions was reported to have reduced the growth of tomatoes, peas, soybeans, and alfalfa plants (15). Additions of soluble beryllium salts at levels equivalent to 4 percent of the cation-absorption capacity of two acid soils reduced the yields of ladino clover. Beryllium at 2 mg/l concentrations in nutrient solutions was found to be toxic to mustard whereas 5 mg/l concentrations were required for growth reductions with kale (16).

d. Bicarbonates

Specific acceptable limits for bicarbonates in irrigation water cannot be prescribed without consideration of other soil and water constituents.

Rationale (Bicarbonates):

High bicarbonate water may induce iron chlorosis by making iron unavailable to plants (17). Problems have been noted with apples and pears (18) and with some ornamentals (19). Although concentrations of 10 to 20 milliequivalents (meq)/l of bicarbonate can cause chlorosis in some plants, it is of little concern in the field where precipitation of calcium carbonate minimizes this hazard.

e. Boron

The maximum acceptable concentration of boron in irrigation water for sensitive crops is 0.75 mg/l; the acceptable concentration for semi-tolerant and tolerant plants is 1.0 and 2.0 mg/l, respectively; and the acceptable concentration for sensitive crops grown on neutral and alkaline fine-textured soils for a period of not more than 20 years is 2.0 mg/l. However, higher concentrations are acceptable for tolerant plants for short periods of time.

Rationale (Boron):

Boron is an essential element for the growth of plants; however, at concentrations of 1 mg/l it is toxic to a number of sensitive plants (1). Lists of boron sensitive, semi-tolerant and tolerant plants are given in USDA Handbook No. 60 (20). In general, sensitive crops show toxicities to boron at 1 mg/l or less, semi-tolerant crops at 1 to 2 mg/l, and tolerant crops at 2 to 4 mg/l. At boron concentrations above 4 mg/l, irrigation water is generally unsatisfactory for most crops. Citrus crops, which are one of the most sensitive crops to boron, show mild toxicity symptoms to irrigation waters having 0.5 to 1.0 mg/l boron (21).

f. Cadmium

The maximum acceptable concentration of cadmium in water for continuous irrigation is 0.01 mg/l. The maximum acceptable concentration in irrigation water for neutral and alkaline fine-textured soils for a period of not more than 20 years is 0.05 mg/l.

Rationale (Cadmium):

Unpublished data (see 1) showed that yields of beans, beets and turnips were reduced about 25 percent by 0.1 mg/l cadmium concentrations in nutrient solutions, whereas, cabbage and barley yields decreased 20 to 50 percent at 1.0 mg/l. Corn and lettuce were intermediate in response with less than 25 percent yield reductions at 0.1 mg/l and greater than 50 percent at 1.0 mg/l.

g. Chlorides

No limit of acceptability is prescribed for chlorides in irrigation waters.

Rationale (Chlorides):

Maximum acceptable limits for chlorides in irrigation water depend upon the type of crop, environmental conditions, and management practices. Chlorides in irrigation waters are not generally toxic to crops; however, certain fruit crops are sensitive to chlorides (1). It has been reported that maximum permissible chloride concentrations in soil ranged from 10 to 50 milliequivalents (meq)/l for certain sensitive fruit crops (22).

h. Chromium

The maximum acceptable concentration of chromium in water for continuous irrigation is 0.1 mg/l. The maximum acceptable concentration in irrigation water for neutral and alkaline fine-textured soils for a period of not more than 20 years is 1.0 mg/l.

Rationale (Chromium):

Concentrations of 10 mg/l of chromium in sand cultures were found to be toxic to corn and concentrations of 5 mg/l and 1.0 mg/l respectively were found to cause reduced growth and stem elongation in tobacco (23). Chromium, as chromic sulfate, was toxic to corn at 5 mg/l in nutrient solutions (24) and chromium as chromic or chromate ions produced iron chlorosis in sugar beets grown in sand cultures (25). Hunter and Vergnano (26) found that 5 mg/l of chromium in nutrient solutions produced iron deficiencies in plants. Because little is known about the accumulation of chromium in soils relative to its toxicity its concentrations in irrigation waters should be held to less than 1 mg/l (see 1).

i. Cobalt

The maximum acceptable concentration of cobalt in water for continuous irrigation is 0.05 mg/l. The maximum acceptable concentration in irrigation water for neutral fine-textured soils for a period of not more than 20 years is 5.0 mg/l.

Rationale (Cobalt):

A concentration of 0.1 mg/l of cobalt in nutrient solutions in irrigation waters is near the threshold toxicity level of plants, whereas a concentration of 0.05 mg/l appears to be satisfactory for continuous application on all soils (1). Because the reaction of this element with soils is strong at neutral and alkaline pH values, and since it increases with time (27), a concentration of 5.0 mg/l might be tolerated by fine-textured neutral to alkaline soils when it is added in small yearly increments (1).

j. Copper

The maximum acceptable concentration of copper in water for continuous irrigation is 0.2 mg/l. The maximum acceptable concentration in irrigation water for neutral and alkaline fine-textured soils for a period of not more than 20 years is 5.0 mg/l.

Rationale (Copper):

Copper concentrations of 0.1 to 1.0 mg/l in nutrient solutions have been shown to be toxic to a large number of plants (28-32). Copper toxicity exhibited an accumulation in soils of 897 kg/hectare (800 lbs/acre) from the use of Bordeaux sprays (33). It is reported that copper toxicity in soils can be reduced by liming the soil if it is acid, using ample phosphate fertilizer, and adding iron salts (34). Toxicity levels in nutrient solutions and limited data on soils suggest a maximum concentration of 0.2 mg/l for continuous use on all soils (1).

k. Fluoride

The maximum acceptable concentration of fluoride in water for continuous irrigation on all soils is 2.0 mg/l. The maximum acceptable concentration for continuous irrigation of acid sandy soils is 1.0 mg/l. The maximum acceptable concentration for neutral and alkaline fine-textured soils for a period of not more than 20 years is 15.0 mg/l.

Rationale (Fluoride):

Application of soluble fluoride salts to acid soils can produce toxicity to plants (1). It was shown that 404 kg of fluoride per hectare (360 lbs/acre) added as sodium fluoride, reduced the yields of buckwheat at a pH of 4.5, but at pH values above 5.5 this rate produced no injuries to the plants (35).

1. Iron

The maximum acceptable concentration of iron in water for continuous irrigation is 5.0 mg/l. The maximum acceptable concentration in irrigation water for neutral to alkaline soils for a period of not more than 20 years is 20 mg/l.

Rationale (Iron):

Iron is so insoluble in aerated soils at all pH values in which plants grow well that it is not toxic (1). However, Rhoads (36) found large reductions in the quality of cigar wrapper tobacco due to the precipitation of iron oxides on the leaves when the plants were sprinkler irrigated with water containing 5 or more mg/l soluble iron. Also, soluble iron salts in irrigation water contribute to soil acidification and the precipitated iron increases the fixation of such essential elements as phosphorus and molybdenum (1).

m. Lead

The maximum acceptable concentration of lead in water for continuous irrigation is 5.0 mg/l. The maximum acceptable concentration in irrigation water for neutral and alkaline fine-textured soils for a period of not more than 20 years is 10.0 mg/l.

Rationale (Lead):

The phytotoxicity of lead is relatively low (1). Since soluble lead contents in soils are usually from 0.05 to 5.0 mg/kg (37) little toxicity can be expected (1). Although it was concluded (38) that lead as it occurs in nature is toxic to vegetation, studies using some plant roots and high concentrations of lead revealed it to be concentrated in cell walls and nuclei and to be an inhibitor of cell proliferation (see 1).

n. Lithium

The maximum acceptable concentration of lithium in water for continuous irrigation is 2.5 mg/l except for citrus where 0.075 mg/l is the maximum acceptable concentration.

Rationale (Lithium):

Most crops can tolerate lithium in nutrient solutions at concentrations up to 5 mg/l (39, 40); however, citrus crops are more sensitive to lithium (41, 42, 43). Grapefruit developed severe symptoms of toxicity when irrigated with water containing concentrations of lithium from 0.18 to 0.25 mg/l (43). A slight toxicity of lithium to citrus was noted when concentrations of lithium were from 0.06 to 0.1 mg/l (44).

o. Manganese

The maximum acceptable concentration of manganese in water for continuous irrigation is 0.2 mg/l. The maximum acceptable concentration in irrigation water for neutral and alkaline fine-textured soils for a period of not more than 20 years is 10.0 mg/l. Concentrations for continued application may be increased for alkaline or calcareous soils and also with crops that have higher tolerance levels.

Rationale (Manganese):

Manganese concentrations at a few tenths to a few milligrams per liter in nutrient solutions are toxic to a number of crops (44, 47, 48). However, toxicity of this element is associated with acid soils and applications of proper quantities of ground limestone successfully eliminates this problem. Increasing the pH of soils from 5.5 to 6.0 usually reduces the active manganese to below toxic levels (48).

p. Molybdenum

The maximum acceptable concentration of molybdenum in water for continuous irrigation on all types of soils is 0.01 mg/l. The maximum acceptable concentration in irrigation water for short term application on soils that react with this element is 0.05 mg/l.

Rationale (Molybdenum):

This element presents no problems of toxicity to plants at concentrations usually found in soils and waters. However, the problem is one of toxicity to animals ingesting the forage that has been grown in soils with relatively high amounts of available molybdenum (1). It was reported that the molybdenum concentrations in forage of 5 to 30 mg/kg produced toxicity to ruminants (49). The accumulation of molybdenum in plants was found to be proportional to the amount of the element added to the soil. Molybdenum concentrations of 0.01 mg/l or greater in soil were associated with animal toxicity levels of this element in alsike clover (51).

q. Nickel

The maximum acceptable concentration of nickel in water for continuous irrigation on all types of soils is 0.2 mg/l. The maximum acceptable concentration in irrigation water for neutral fine-textured soils for a period of not more than 20 years is 2.0 mg/l.

Rationale (Nickel):

Many experiments with plants in solution cultures have shown that nickel at 0.5 to 1.0 mg/l is toxic (52). Increasing the pH of soils reduces the toxicity of added nickel (52, 53, 54). The greatest capacity to adsorb nickel without development of toxicity to plants was exhibited by soils with 21 percent organic matter (54).

r. Nitrates

No maximum limit of acceptability is prescribed for nitrates in irrigation waters.

Rationale (Nitrate):

Nitrates in irrigation waters are usually an asset for plant growth, and there is no apparent evidence that they will accumulate to toxic levels in irrigated plants (1).

s. Selenium

The maximum acceptable concentration of selenium in irrigation water is 0.02 mg/l.

Rationale (Selenium):

Selenium is toxic at low concentrations in nutrient solutions and small amounts added to soils increase the selenium content in forage to levels which are toxic to livestock (1). Amounts of selenium in forage required to prevent selenium deficiencies in cattle range between 0.03 and 0.10 mg/kg (55); whereas, concentrations above 3 or 4 mg/kg are toxic (56).

t. Sodium

No limit of acceptability is prescribed for sodium in irrigation waters. Acceptable sodium concentrations should be prescribed individually based on its hazard to specific crops and using limits determined by the U.S. Salinity Laboratory.

Rationale (Sodium):

The complex interactions of sodium ions with other common ions upon various crops precludes a consideration as an individual component for limits in irrigation water except where fruit crops may be important (1). Sodium is adsorbed by lemons, avocados and stoned fruits grown in cultured solutions and causes leaf burns to these plants (60, 61). It is difficult to separate the specific toxic effects of sodium from the effects of adsorbed sodium on soil structure (1).

4. Pathogens

a. Human Pathogens

The maximum acceptable density of fecal coliforms in irrigation water is 1,000/100 ml.

Rationale (Human Pathogens):

Irrigation waters with fecal coliform densities of 1,000/100 ml are believed to contain sufficiently low concentrations of pathogenic microorganisms that no hazards to animals or man result from their use or from consumption of raw crops irrigated with such waters (1). Many microorganisms pathogenic to animals may be carried in irrigation water, particularly that derived from surface sources. This includes a large variety of bacteria which find their way into irrigation water from municipal and industrial wastes including food processing plants, slaughter houses, poultry processing operations and feed lots. The diseases associated with such bacteria include bacillary and amoebic dysentery, Salmonella gastroenteritis, typhoid and paratyphoid fevers, leptospirosis, chlorea, vibriosis, and infectious hepatitis. Recent studies have emphasized the value of fecal coliform density in assessing the occurrence of Salmonella, the most common bacterial pathogen in irrigation water (1). Geldreich and Dordner (62) reviewed field studies involving irrigation water, field crops and soils and stated that when the fecal coliform density in stream waters exceeded 1,000 organisms per 100 ml, Salmonella occurrence reached a frequency of 96.4 percent. Below 1,000 fecal coliforms per 100 ml (range 1 - 1,000) the occurrence of Salmonella was 53.5 percent.

b. Plant Pathogens

In order to protect plants from disease pathogens in irrigation water, it is necessary to take preventive measures rather than establish quantitative assay limits. Disposing of diseased plant material in lakes, streams, or irrigation systems should be avoided.

Rationale (Plant Pathogens):

Irrigation water may be assayed for plant pathogens; however, there are thousands or perhaps millions of harmless microorganisms for every one that causes a plant disease. Plant infection is not considered serious unless an economically important percentage of a crop is affected. The real danger is that a plant disease can be spread by water to an unaffected area, where it can then be spread by other means and become important. It is unlikely that any method of water examination or any limits in water would be as effective in preventing this as would be prohibitions upon the introduction of diseased material into water that may be used for irrigation (1).

5. Pesticides

a. Herbicides

The maximum acceptable concentrations of dalapon, TCA and 2,4-D amine salt in irrigation water are 0.2, 0.2, and 0.1 ug/l respectively.

Rationale (Herbicides):

It is reported (1) that significant levels of herbicides are likely to be found in irrigation water under the following circumstances: a) during their purposeful introduction into the water to control submerged weeds or b) incidental to herbicide treatment for control of weeds on banks of irrigation canals. Water use restrictions are usually applied when herbicides are used in reservoirs of irrigation water. Herbicides used in reservoirs are persistent and inherently phytotoxic to plants at low levels. Also, the most widely used herbicides on irrigation ditch banks are 2,4-D, dalapon, TCA, and silvex, which are readily soluble in water and not extensively adsorbed to soil or other surfaces (1). Reduction in levels of residues in flowing irrigation waters is due largely to dilution (1).

b. Insecticides

No limit of acceptability is prescribed for insecticide concentrations in irrigation waters.

Rationale (Insecticides):

Concentrations of insecticides normally occurring in irrigation water are not detrimental to crops. There are no documented cases of insecticide residues in irrigation waters being toxic to plants. Because of this and the marked variability in crop sensitivities, no limits for insecticides in irrigation waters are necessary (1).

6. Radioactivity

An acceptable concentration of radionuclides in irrigation water depends on the amount of radioactivity transferred to the foodstuffs and shall be such that the total radionuclide ingestion by the most exposed group using the food will not exceed the daily intake prescribed in Federal Drinking Water Standards. If the consumption of these foodstuffs is so widespread that it is likely that the aggregate dose to the exposed population will exceed 3000 man-rem per year, limitations on the distribution and sale should be considered by the relevant public health authorities.

Rationale (Radioactivity):

There are no generally acceptable concentration limits for control of radioactive contamination in irrigation water since the amount of radioactivity in the food will vary depending on the type of crop, soil, and duration and method of irrigation. However, only in highly unusual circumstances will irrigation waters meeting Federal Drinking Water Standards for radioactivity be unsuitable for any agricultural use.

7. Solids

a. Solids (Dissolved)

The maximum acceptable concentrations of total dissolved solids in irrigation waters are 2,000 - 5,000 mg/l for tolerant plants in permeable soils or 500 - 1,000 mg/l for sensitive crops.

Rationale (Dissolved Solids):

In spite of the facts that: a) any total dissolved solids (TDS) limits used in classifying the salinity hazards of waters are somewhat arbitrary; b) the hazard is related not only to the TDS but also to the individual ions involved; and c) no exact hazard can be assessed unless the soil crop and accessible yield reductions are known; certain classifications of limits of certain dissolved solids in irrigation water are useful. Waters with total dissolved solids less than about 500 mg/l are usually used by farmers without awareness of any salinity problems, unless there is a high water table (1). Without dilution from precipitation or an alternate supply, waters with TDS of about 5,000 mg/l usually have little value for irrigation (64). Within these limits the values of the water appear to decrease as the salinity increases. Where water is to be used regularly for the irrigation of relatively impervious soils, its value is limited if the TDS is in the range of 2,000 mg/l or higher (1).

b. Solids (Suspended)

No limit of acceptability is prescribed for suspended solids in irrigation waters.

Rationale (Suspended Solids):

Although they can be detrimental to seedling emergence and leafy plant development, irrigation waters containing sediments high in silt may improve the texture, consistency, and water holding capacity of sandy soils (1). Deposition of colloidal particles on the soil surface can produce a crust that inhibits water infiltration and seedling emergence, while the same deposition and crusting can reduce soil aeration and impede plant development (1). High colloidal content in water used for sprinkler irrigation can result in deposition of films on leaf surfaces that reduce photosynthetic activity and thereby deter growth as well as affecting the marketability of leafy vegetable crops such as lettuce (1).

8. Temperature

No limit of acceptability for temperature is prescribed for irrigation waters.

Rationale (Temperature):

The temperature of irrigation water has both direct and indirect effects on plant growth. Each occurs when plant physiological functions are impaired by excessively high or excessively low temperatures. The exact water temperature at which growth is severely restricted depends upon method of water application, atmospheric conditions at the time of application, frequency of application, and plant species. Optimum temperatures for growth vary considerably by species. Direct effects on plant growth from extreme temperatures of irrigation water occur when water is first applied, with plant damage resulting only from direct contact. Excessively warm water applied through a sprinkler system has little effect upon the plant. Water as warm as 55°C (130°F) can be safely applied in this manner as warm water frequently reaches ambient temperatures by the time it reaches the soil (65). Cold water, however, applied through a sprinkler system may be harmful to plant growth as ambient temperatures are not attained as rapidly with cold water as they are with warm water (1).

The indirect effects of the temperature of irrigation water on plant growth occur as a result of the influence of the water temperature upon the soil. It is well documented that soil temperatures affect the rate of water and nutrient uptake, translocation of metabolites and other physiological processes (1). The effect of the temperature of irrigation waters upon the temperature of the soil is not well known, but this effect is thought to be small (1).

C. Livestock

1. Inorganics (Ions and Free Elements/Compounds)

a. Aluminum

The maximum acceptable concentration of aluminum in livestock drinking water is 5.0 mg/l.

Rationale (Aluminum):

The occurrence of aluminum in water should not cause problems for livestock except under unusual conditions and with acid waters (1).

b. Arsenic

The maximum acceptable concentration of arsenic in livestock drinking water is 0.2 mg/l.

Rationale (Arsenic):

The toxicity of arsenic depends on its chemical form. Its organic oxides are considerably more toxic than the organic forms which occur in living tissues or are used as feed additives. Differences in toxicities of the various forms are clearly related to the rate of their excretion, the least toxic being the most rapidly eliminated (66, 67). Except in unusual cases, arsenic normally occurs in waters largely as inorganic oxides (1). The acute toxicity of inorganic arsenic for farm animals was given (68) as follows: poultry, 0.05 - 0.10 g per animal; swine, 0.15 - 1.0 g per animal; sheep, goats, and horses, 10.0 - 15.0 g per animal; and cattle, 15.0 - 30.0 g per animal. Arsenic acid at levels up to 1.25 mg/kg of body weight per day was fed (68) to lactating cows for eight weeks. This is equivalent to an intake of 60 liters of water containing 5.5 mg/l of arsenic daily by a 500 kg animal. Results indicated that this form of arsenic is absorbed and rapidly excreted in the urine and that there was no increase of the arsenic content of the milk. No toxicity was observed.

c. Beryllium

No limit of acceptability is prescribed for beryllium concentrations in livestock drinking water.

Rationale (Beryllium):

The salts of beryllium are not highly toxic. Laboratory rats survived for two years on a diet that supplied the element at a level of about 18 mg/kg body weight daily (1). It was calculated (70) that a cow could drink almost 1,000 liters of water containing 6,000 mg/l without harm if the data from rats are transposable to cattle. Little additional data exists on the toxicity of beryllium to livestock (see 1).

d. Boron

The maximum acceptable concentration of boron in livestock drinking water is 5.0 mg/l.

Rationale (Boron):

Boron has relatively low order of toxicity to livestock (1). In the dairy cow 16-20 g of boric acid per day for 40 days produced no ill effects (71). There is no evidence that boron accumulates to any extent in body tissues (1).

e. Cadmium

The maximum acceptable concentration of cadmium in livestock drinking water is 50.0 ug/l.

Rationale (Cadmium):

Research to date suggests that cadmium is not an essential element but, on the other hand, is quite toxic. Man has been sickened by doses as low as 15 mg/l in popsicles (71). It was found (72) that a single dose of 4.5 mg cadmium/kg of body weight produced permanent sterility in male rats. At a level of 5 mg/l in the drinking water of rats (73) or mice (74) cadmium reduces longevity. Intravenous injections of cadmium sulfate into pregnant hamsters at a level of 2 mg/kg body weight on day eight of gestation caused malformations in the fetus (75). It was found (76) that only a small part of ingested cadmium in ruminants was absorbed, with most of that going to the kidneys and liver. Once absorbed its turnover rate was very slow. The cow was found to be very efficient in keeping cadmium out of its milk, and it was concluded that most major animal products, including beef and milk, seem quite well protected against cadmium accumulation (76).

f. Chromium

The maximum acceptable concentration of chromium in livestock drinking water is 1.0 mg/l.

Rationale (Chromium):

Even in its most soluble forms, chromium is not readily absorbed by animals, being largely excreted in the feces (1). Also, it does not appear to concentrate in any particular mammalian tissues or to increase in these tissues with age (66, 77). After review of chromium toxicity it was suggested (71) that up to 5 mg/l of chromium III or VI in livestock drinking water should not be harmful. While this may be reasonable it is suggested that this level may be unnecessarily high and the prescribed 1.0 mg/l chromium level was therefore recommended to provide a suitable margin of safety (1).

g. Cobalt

The maximum acceptable concentration of cobalt in livestock drinking water is 1.0 mg/l.

Rationale (Cobalt):

Cobalt is part of the vitamin B_{12} molecule and as such, it is an essential nutrient. Ruminants synthesize their own vitamin B_{12} if they have cobalt in their diet. For cattle and sheep a diet containing about 0.1 mg/kg of the element appears to be nutritionally adequate (1). A wide margin of safety exists between the required and toxic levels for sheep and cattle, which are levels of a hundred times those usually found in diets that are well tolerated (1). When vitamin B_{12} is administered to non-ruminants in amounts well beyond those present in food and feeds, cobalt induces polycythemia (67). This is also true for calves prior to rumen development where about 1.1 mg of this element per kg of body weight administered daily causes depression of appetite and loss of weight. The prescribed 1.0 mg/l cobalt level is recommended (1) based upon available toxicity data as offering a satisfactory margin of safety for livestock.

h. Copper

The maximum acceptable concentration of copper in livestock drinking water is 0.5 mg/l.

Rationale (Copper):

Copper is an essential trace element to animals and some of it is required in their diet. Swine are apparently very tolerant of high levels of copper and 250 mg/kg or more in the diet have been used to improve live weight gains and feed efficiency (78, 79). It does not appear to accumulate in muscle tissues and apparently is readily eliminated upon cessation of intake (1). On the other hand, sheep are very susceptible to copper poisoning and a diet containing 25 mg/kg is considered toxic (67). About 9 mg per animal per day is considered as a safe level of intake (80). There are little experimental data on effects of copper in livestock drinking water, and its toxicity must be judged largely from the results of test feedings.

i. Fluorine

The maximum acceptable concentration of fluorine in livestock drinking water is 2.0 mg/l.

Rationale (Fluorine):

A level of 2.0 mg/l in livestock drinking water may result in some tooth mottling; however, it is not excessive from the standpoint of animal health or the deposition of this element in meat, milk or eggs (1). Chronic fluoride poisoning of livestock has been observed where water contained 10 to 15 mg/l fluoride (67). Concentrations of 30 - 50 mg/l of fluoride in the total ration of dairy cows is considered the upper safe limit (81). Fluoride from waters apparently does not accumulate in soft tissue to a significant degree and it is transferred to a very small extent into the milk and to a somewhat greater degree into eggs (67). It was concluded (71) that 1.0 mg/l of fluorine in drinking water did not harm livestock.

j. Iron

No limit of acceptability is prescribed for iron in livestock drinking water.

Rationale (Iron):

Iron is essential to animal life and it has a very low order of toxicity (1). Very high levels of iron in the diet (4,000 and 5,000 mg/kg) were found to cause phosphorus deficiency and to be toxic to weanling pigs (82); however, lower levels (3,000 mg/kg) apparently were not toxic. While iron occurs in natural water as very soluble ferrous salts, on contact with air they are oxidized and precipitated as ferric oxide, rendering them essentially harmless to animal life. It is therefore not considered necessary to set a limit for this element (1).

k. Lead

The maximum acceptable concentration of lead in livestock drinking water is 0.1 mg/l.

Rationale (Lead):

A nutritional need for lead by animals has not been demonstrated, but its toxicity is well known (1). A rather complete review of the matter of lead poisoning suggested (71) that for livestock the toxicity of this element had not been clearly established from a quantitive standpoint. Although a daily intake of 6 - 7 mg/kg of body weight has been suggested as a threshold poisoning level in cattle (89), and even with more recent data (83 - 88), it is difficult to clearly establish the intake level at which lead becomes toxic. There is agreement that 0.5 mg/l of lead in the drinking water of livestock is a safe level (71). Other findings (73, 74, 90, 91) based upon studies with laboratory animals are also in agreement with this level. At 5 mg/l lead in the drinking water of rats and mice over their life spans, the same investigators found no obvious direct toxic effects. They did, however, find an increase in the death rates of older animals, especially in the males. It was observed (91) that the increased mortality was not caused by overt lead poisoning, but rather by increase of susceptiblilty to spontaneous infections. It was reported (92) that mice treated with subclinical doses of lead nitrate were more susceptible to infections from *Salmonella typhimurium*.

l. Manganese

No limit of acceptability is prescribed for concentrations of manganese in livestock drinking water.

Rationale (Manganese):

Manganese is a required trace element, occurring in natural waters at only low levels as manganous salts, and is precipitated in the presence of air as manganic oxide (1). While it can be toxic when administered in livestock feed at high levels (67) it is improbable that it would be found at toxic levels in water (1).

m. Mercury

The maximum acceptable concentration of mercury in livestock drinking water is 1.0 ug/l.

Rationale (Mercury):

Concentrations of mercury in surface waters have usually been found to be far less than 5 ug/l (68), but methylation of bottom sediment mercury in areas bordering mercury deposits results in a continuous presence of the element in solution (69, 70). The relative stability of methylmercury together with efficient absorption of it by the gut contributes to its increased toxicity when orally administered (70). It is suggested (1) that maintenance levels of mercury in livestock blood and tissues not exceed 0.1 mg/l and 0.5 mg/kg respectively to provide a safe level for human consumption. The safe level for consumption of fish as prescribed by the Food and Drug Administration is also 0.5 mg/kg. However, the maintenance level for fish was predicated upon the fact that there are no other sources of mercury in the diet than from fish. In view of these facts the limits prescribed herein are reduced by a factor of ten to reduce the significance of levels from meat products in comparison with those of fish.

n. Molybdenum

No limit of acceptability is prescribed for concentrations of molybdenum in livestock drinking water.

Rationale (Molybdenum):

Too many factors influence the toxicity of molybdenum to permit the establishment of limits on concentrations in water for livestock drinking. It has been pointed out (67) that many of the previous studies on the toxicities of molybdenum are of limited value because a number of factors known to influence its metabolism were not taken into account in making these studies. These factors include the chemical form of molybdenum, the copper status and intake of the animal, the form and amount of sulfur in the diet, and other less well defined entities. In spite of these, there are considerable data to support real species differences in terms of tolerance to this element. Cattle seemed the least tolerant, sheep a little more so, and horses and swine considerably more tolerant (1).

o. Nitrates and Nitrites

The maximum acceptable concentration of nitrates plus nitrites in livestock drinking water or in water to be used in feed slurries is 100.0 mg/l. The maximum acceptable concentration of nitrite alone is 10.0 mg/l.

Rationale (Nitrates and Nitrites):

Nitrites are considerably more toxic to livestock than nitrates. Usually nitrite is formed through the biological reduction of nitrate in the rumen of cattle or sheep, in freshly chopped forage, in moistened feeds, or in water contaminated with organic matter to the extent that it is capable of supporting microbial growth. While natural waters often contain high levels of nitrate, their nitrite content is usually very low (1). It was concluded (93) that nitrate in cattle feed does not appear to constitute a hazard to human health, and that animals fed nitrate continuously develop some degree of adaption to it. The LD_{50} of nitrate nitrogen for ruminants was found to be about 75 mg/kg of body weight when administered as a drench (94) and about 255 mg/kg of body weight when sprayed on forage and feed (95). Assuming a maximum water consumption in dairy cattle of 3 - 4 times the dry matter intake, the concentration of nitrate to be tolerated in the water should be about one fourth of that tolerated in the feed (1). This would amount to about 300 mg/l of nitrate. Drinking water containing 330 mg/l nitrates fed continuously to growing pigs and to gilts from weaning through two furrowing seasons had no adverse effects (96). Levels of nitrate up to 300 mg/l were added to drinking water without adversely affecting the growth of chicks or production of laying hens (97). Losses in swine due to methoglobinemia have occurred only with the consumption of preformed nitrite and not with nitrate (98 - 100). In special situations involving the presence of high levels of nitrates in aqueous slurries of plant or animal tissues, nitrite accumulation reached a peak of about one fourth to one half the initial nitrate concentration (98 - 101). Levels of nitrite up to 200 mg/l were added to drinking waters without adverse effect on the growth of chicks or production of laying hens (97). At 200 mg/l, nitrite decreased growth in turkey pullets and reduced the liver storage of vitamin A in chicks, laying hens, and turkeys. At 50 mg/l nitrite, no effects were observed on any of the birds. It appears that all classes of livestock and poultry which have been studied under controlled experimental conditions can tolerate the continued ingestion of waters containing up to 300 mg/l of nitrate or 100 mg/l of nitrite (1).

p. Selenium

The maximum acceptable concentration of selenium in livestock drinking water is 0.05 mg/l.

Rationale (Selenium):

No substantiated cases of livestock poisoning by selenium in waters have been reported, although some spring and irrigation waters have been found to contain over 1 mg/l of this element (102 - 104). As a rule, well, surface, and ocean waters contain less than 0.05 mg/l, usually considerably less (1). The low selenium content as has been explained (105) results from the precipitation of the selenite ion with ferric hydroxide. Another explanation may be that microbial activity removes both selenite and selenate from water (106). A study with rats (107) revealed that selenite but not selenate in livestock drinking water caused deaths at a level of 2 mg/l and was somewhat more toxic than selenite administered in the diet.

q. Vanadium

The maximum acceptable concentration of vanadium in livestock drinking water is 0.1 mg/l.

Rationale (Vanadium):

Vanadium becomes toxic to chicks when incorporated into the diet as ammonium metavanadate at concentrations over about 10 mg/kg (108 - 111). It was found (73) that when mice drank water containing 5 mg/l of vanadium as vanadyl sulfate over a life span, no toxic effects were observed, but this element did accumulate to some extent in certain organs.

r. Zinc

The maximum acceptable concentration of zinc in livestock drinking water is 25.0 mg/l.

Rationale (Zinc):

Zinc is relatively non-toxic to animals (1). Swine have tolerated 1,000 mg/kg of dietary zinc (112 - 115), while 2,000 mg/kg or more have been found to be toxic. Similar findings have been reported for poultry (116 - 118) when zinc was added to the feed. Adding 2,320 mg/l of the element to water for chickens reduced water consumption, egg production, and body weight (119). In a number of studies with ruminants, it was found (120 -123) that zinc added to diets as an oxide tended to be toxic, but at levels over 500 mg/kg of diet. While an increase of zinc intake reflects an increase of the levels of this element in the body tissue, a tendency for its accumulation was not great (124, 125, 126, 114) and tissue levels fell rapidly after zinc dosing was stopped (124, 117).

2. Pathogens

a. Microorganisms

The maximum acceptable limit for livestock drinking water is 5,000 coliforms per 100 ml of water. The maximum acceptable monthly arithmetic density of fecal coliforms is 1,000 per 100 ml of water. Both limits are to be based upon an average of at least two consecutive samples examined per month. The maximum acceptable limit of any one sample examined in any one month is a total coliform count of 20,000 per 100 ml of water or a fecal coliform density of 4,000 per 100 ml of water.

Rationale (Microorganisms):

As an index of fecal pollution the total coliform and fecal coliform group of bacteria best serve as an indicator to the degree of contamination. Transmitted to livestock by water is a variety of microorganisms associated with both feces and urine. However, none of these organisms except the fecal coliform group are quantifiable or standardized to such a degree as to permit specific limits for water quality criteria. Hence the use of the fecal and total coliform standards.

b. Toxic Algae

Heavy growths of toxic blue-green algae are not acceptable in livestock drinking water supplies.

Rationale (Toxic Algae):

A number of cases of algae poisoning in farm animals in Minnesota were reviewed (127) between 1882 and 1933. All were associated with certain blue-green algae, often concentrated by the wind at one end of the lake. Six species of blue green algae have been incriminated (128) in the poisoning of livestock. These are: *Nodularia spumigena*, *Microcystis aeruginosa*, *Coelosphaerium kuetzingianum*, *Gloeotrichia ecinulata*, *Anabaena flos-aquae*, and *Aphanizomenon flos-aquae*. Of the previous, it was reported (128) that *Microcystis* and *Anabaena* have most often been blamed for serious poisonings of livestock, and algae blooms consisting of one or more of these species vary considerably in their toxicity. This variability seems to depend upon a number of factors, e.g., species or strains of algae that are predominant; types and number of bacterial associates; the condition of growth, collection and decomposition; the degree of animal starvation and susceptibility; and the amounts consumed (129). It has been evinced (130) that sudden decomposition of algae blooms often preceded mass mortality of fish, and similar observations have been made with livestock poisoning. This suggests that the lysis of the algae may be important in the release of the toxicants. But it also suggests that in some circumstances botulism may be involved.

3. Pesticides

The maximum acceptable concentrations of pesticides in livestock drinking water correspond to those prescribed for public drinking water supplies.

Rationale (Pesticides):

Field studies indicate no deleterious effects on the health of animals due to pesticide residues in livestock drinking water (1). However, inherent problems associated with pesticide use include the accumulation and secretion of either the parent compound or its degradation product in edible tissues and milk (131). Nonpolar lipophilic (fat soluble) pesticides such as the chlorinated hydrocarbon insecticides tend to accumulate in fatty tissue and may result in measurable residues. Polar water soluble pesticides are generally excreted in the urine soon after ingestion. Elimination of fat soluble pesticides from contaminated animals is slow. Urinary excretion is insignificant and the elimination in feces is slow. The primary route of excretion in lactating animals is through milk. Levels of pesticides found in farm water supplies do not make a significant contribution to animal body burden compared to amounts accumulated from feeds (1).

4. Radioactivity

The maximum acceptable concentration of radionuclides in livestock drinking water shall be such that the total radionuclide ingestion by the most exposed group using the livestock as food does not exceed the daily intake prescribed in Federal Drinking Water Standards. If the consumption of these foodstuffs is so widespread that it is likely that the aggregate dose to the exposed population will exceed 3000 man-rem per year, limitations on the distribution and sale should be considered by the relevant public health authorities.

Rationale (Radioactivity):

In some, but not all cases, these criteria permit the utilization of waters unfit for direct human consumption to be used to water livestock, discrimination and subsequent elimination of the radionuclides from the animals serving as a mechanism for radionuclide removal. Where the radionuclide intake is relatively high or where radionuclides are present that may be concentrated in a particular organ, such as the thyroid, radioassay of the foodstuffs may be necessary to determine that acceptable intake limits are not exceeded.

5. Salinity

The maximum acceptable salinity level for livestock drinking water is 3000 mg/l of soluble salts.

Rationale (Salinity):

While some minor physiological upsets resulting from waters with salinity near the prescribed limit may be observed, economic losses or serious physiological disturbances should rarely, if ever, result from their use. It has been found (132) that natural water varying from 4,546 to 7,369 mg/l of total salts, with sodium and sulfate ions predominating, caused mild diarrhea but no symptoms of toxicity in dairy cattle over a two-year period. Also (133), cattle can thrive on water containing 11, 400 mg/l of total salts, can live under some conditions on water containing 17,120 mg/l, and horses can thrive on water containing 5,720 mg/l and are sustained when not worked too hard on water with 9,140 mg/l. The first extensive studies were made (134, 135, 136) of the effects of saline water on rats and livestock. With laying hens, 10,000 mg/l of sodium chloride in drinking water greatly delayed the onset of egg production, but 15,000 mg/l or more were required to affect growth over a ten-week period. In swine, 15,000 mg/l of sodium chloride in the drinking water caused death in the smaller animals and some leg stiffness in the larger animals, but 10,000 mg/l did not appear particularly injurious once they became accustomed to it. Sheep existed on water containing 25,000 mg/l of sodium or calcium chloride or 30,000 mg/l of magnesium sulfates, but not without some deleterious effects. Cattle were somewhat less resistant, and it was concluded that 10,000 mg/l total salts should be considered the upper limit under which their maintenance could be expected. A lower limit was suggested for lactating animals. It was further observed that animals would not drink highly saline solutions if water with a low salt content was available and that animals showing effects of saline water returned quickly to normal when allowed water of a low salt content. Studies (137) of the effects of sodium chloride in water on laying hens, turkey pullets, and ducklings revealed that at 4,000 mg/l, the salt caused some increased water consumption, watery droppings, decreased feed consumption and growth, and increased mortality. These effects were more pronounced at a higher concentration of 10,000 mg/l, causing death in all the turkey pullets at two weeks, some symptoms of dehydration in the chicks, and decreased egg production in the hens.

Experiments with laying hens restricted to water containing 10,000 mg/l of sodium or magnesium sulfates gave results similar to those of sodium chloride. It has been pointed out (1): a) that animals drink little, if any, highly saline water if waters of low salt content are available to them; b) unless they have been previously deprived of water, animals can consume moderate amounts of highly saline water for a few days without being harmed; c) abrupt changes from water of low salinity to high saline water causes more problems than a gradual change; and d) the depressed water intake is very likely to be accompanied by a depressed feed intake.

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V. FRESHWATER CONSTITUENTS

A. Aquatic Life

1. Acidity, Alkalinity and pH

a. pH

The acceptable range of pH is 6.0 to 9.0. Changes of up to 0.5 units from the estimated natural seasonal minimum and maximum are acceptable. For natural waters having a pH outside the 6.0 to 9.0 range or having fluctuations in excess of 0.5 units from the estimated natural seasonal minimum and maximum, no further variance is acceptable.

b. Alkalinity

Decreases in the total alkalinity of water of more than 25 percent below the natural level are unacceptable.

c. Acidity

Additions of weakly dissociated acids and alkalies are generally unacceptable.

Rationale (Acidity, Alkalinity and pH):

Extremes of pH can exert stress conditions or kill aquatic life outright. Even moderate changes from "acceptable" criteria limits of pH are deleterious to some aquatic species. Non-lethal limits are narrower for certain fish food organisms than they are for fish. *Daphnia magna* and *Gammarus* for example, do not reproduce at pH levels below 6.0. Alkaline conditions above pH 8.5 begin to decrease fecundity of many fish species. Addition of strong alkalies can cause an increase in the proportion of un-ionized ammonia, the toxic component. Metallo-cyanide complexes can increase a thousand fold in toxicity with a drop of 1.5 pH units. The availability of many nutrient substances varies with the alkalinity and acidity, i.e., iron becomes unavailable to plants at high pH values (See 1).

2. Dissolved Gases

a. Ammonia

The maximum acceptable concentration of un-ionized ammonia (NH_3) in water is 1/20 (0.05) the 96-hour LC_{50}. When appropriate this value will be determined using the receiving water in question and the most sensitive important species in the locality as the test organisms. The acceptable maximum concentration of un-ionized ammonia in water is 0.02 mg/l.

Rationale (Ammonia):

The toxicity of ammonia solutions is dependent upon the un-ionized ammonia, the concentrations of which vary with the pH of the water. In most natural water the pH range is such that ammonium ions (NH_4^+) predominate, however, in alkaline waters high concentrations of un-ionized ammonia in undissociated ammonium hydroxide increase the toxicity of ammonia solutions (see 1 and 2). In streams polluted with sewage, up to one half of the nitrogen in the sewage may be in the form of free ammonia, and sewage may carry up to 35 mg/l of total nitrogen (3 cited in 4). Acute toxicity data compiled on several species of fish yielded mean 96-hour LC_{50} values ranging from 0.29 to 0.89 mg/l (1). An application factor of 0.05 applied to these data produced values in the neighborhood of 0.02 mg/l which is about one-half the values cited (5) as the no effect level for rainbow trout.

b. Chlorine and Related Compounds

The maximum acceptable residual chlorine concentrations in water are 0.003 mg/l for chronic exposure. Maximum concentrations of residual chlorine of 0.05 mg/l for a period of up to 30 minutes in any 24-hour period are acceptable.

Rationale (Chlorine):

The toxicity of chlorine in water to aquatic life depends upon the concentration of residual chlorine and the relative amounts of free chlorine and chloramines (6). Apparently the toxicity of free chlorine in water is in the same order as that of the chloramines, and the toxicity of chlorine can generally be estimated from a measure of residual chlorine (7, 8). LC_{50} residual chlorine levels for fish have been reported at 0.008 mg/l in seven days (8), and 0.05 - 0.19 mg/l (9) and 0.23 mg/l (10) in 96-hours. In chronic tests, fecundity of fathead minnows was reduced by exposure to 0.043 mg/l total chloramines, and survival and reproduction of Gammarus were reduced by exposure to 0.04 - 0.0034 mg/l, respectively (11). It was postulated (8) that exposure to concentrations of 0.004 mg/l for one year would permit survival of one-half of the test fish. Apparently aquatic organisms can tolerate short term exposure to higher level residues of chlorine without harmful effects; however, chronic exposure tc concentrations in excess of 0.003 mg/l could cause chronic toxic effects.

c. Dissolved Oxygen

(1). Minimum acceptable limits of dissolved oxygen for all water shall be based upon seasonal temperatures. Minimum acceptable limits are presented in the table below:

°C	Oxygen Levels for Complete Saturation	Minimal Levels for Protection of Salmonid Spawning	Minimal Levels for Protection of Aquatic Life
36	7 mg/l	6.4 mg/l	5.8 mg/l
27.5	8 mg/l	7.1 mg/l	5.8 mg/l
21	9 mg/l	7.7 mg/l	6.2 mg/l
16	10 mg/l	8.2 mg/l	6.5 mg/l
7.7	12 mg/l	8.9 mg/l	6.8 mg/l
1.5	14 mg/l	9.3 mg/l	6.8 mg/l

(2). As an exception, under extreme conditions for short periods of not more than 24 hours, a minimum limit of 4 mg/l is acceptable for waters above 31°C (87.8°F).

Rationale (Dissolved Oxygen):

The prescribed limits of acceptability were derived from calculations (1) based upon extensive studies of the effects of changes in dissolved oxygen. These dissolved oxygen limits should provide a high level of protection for freshwater aquatic life and preclude their impairment by other necessary multiple uses of water. Oxygen requirements of aquatic life have been the subject of numerous investigations, and several excellent survey papers on the subject have been compiled and are reviewed (1). Although most investigations have dealt specifically with the oxygen requirements of fish, it is generally acknowledged that the requirements of fish and their forage organisms are compatible. That is, aquatic environments with oxygen levels which are adequate to sustain a fish population will also support invertebrates if other habitat requirements are met. In establishing criteria, it is important to know not only how long an animal can resist death by asphyxiation at low dissolved oxygen concentrations, but also information must be available on the oxygen requirements for egg development, for newly hatched larvae, for normal growth and activity, and for completing all stages of the reproductive cycle. Upon review of the available information, one fact becomes clear: any reduction of dissolved oxygen can reduce the efficiency of oxygen uptake by aquatic animals, and hence reduce their ability to meet demands of their environment. There is evidently no concentration level or percentage of saturation to which the dissolved oxygen content of natural waters can be reduced without causing or risking some adverse effects on the reproduction, growth, and consequently, the production of fishes inhabiting those waters (1). The selection of the level of protection to be afforded aquatic life by the establishment of numerical criteria is influenced by socio-economic as well as biological consideration. Consequently, the intent of the criteria is to provide a level of protection for diversified species rather than single limits in an effort to protect only specific organisms. Deleterious effects on fish seem to depend more on extremes than on averages (1). The dissolved oxygen criteria are therefore based upon temperature and degree of oxygen saturation. For example, fish occupying a habitat which is well saturated with oxygen during daylight hours may be subjected to stress conditions in the early morning hours when the oxygen demand has exhausted the photosynthetic reserve. Although there is no single oxygen concentration which is favorable to all species and ecosystems, there are definite minimal concentrations that are unfavorable to almost all aquatic organisms (1). To provide for short duration physical anomalies and for the case when lower minimum ambient oxygen concentrations cannot be determined at higher temperature levels, a floor of 4 mg/l is established. Available information indicates that below this minimal concentration subacute or chronic damage to several fish has been demonstrated.

d. Hydrogen Sulfide

The maximum acceptable concentrations of hydrogen sulfide in water are 0.002 mg/l.

Rationale (Hydrogen Sulfide):

See sulfides.

e. Nitrogen and Gas Bubble Disease

The maximum acceptable total dissolved gas pressure in water is 110 percent of the existing atmospheric pressure, and any prolonged artificial increase or sudden decrease in total dissolved gas pressure should be avoided.

Rationale (Nitrogen and Gas Bubble Disease):

Gas bubble disease is caused by excessive total dissolved gas pressure (supersaturation), but it is not caused by the dissolved nitrogen gas alone (12 - 17). Analysis of gases in bubbles formed in fish suffering from the disease revealed compositions essentially identical to air (18, 19). Gas bubble disease is frequently associated with supersaturated waters and has been related to high reaeration rates resulting from algal blooms (16), heated effluents of steam generating plants (20, 21) and dam spillways (22, 23). Gas bubble disease results in bubble formation on and within the fish. Gas emboli eventually cause hemostasis within the blood vessels, resulting in tissue damage and gas formation in the heart leading to death (1). Sublethal effects of gas bubble disease include the promotion of other diseases, necrosis, tissue changes, blindness and reproductive failure (22 - 26). The response of fish to gas bubble disease varies with life stages and species, degree of fatness, blood pressure, blood viscosity, metabolic heat, body size, muscular activity and blood osmolarity (1). There are few data on the tolerance of invertebrates to excessive dissolved gas pressure; however, it has been demonstrated that certain invertebrates develop gas pressure disease (see 1). Due to the paucity of data on chronic sublethal effects of gas bubble disease on fish, and to the lack of knowledge of the disease in invertebrates, safe limits must be judged from data on mortality of selected fishes under conditions approximating the water of a hypothetical littoral zone (1). These data indicate that if total gas pressures do not exceed 110 percent of the existing atmospheric pressure, aquatic life should be adequately protected.

3. Inorganics (Ions and Free Elements/Compounds)

a. Cadmium

Maximum acceptable cadmium concentrations are 0.03 mg/l in hard water (total hardness greater than 100 mg/l as $CaCO_3$) and 0.004 mg/l in soft water (total hardness 100 mg/l $CaCO_3$ or less). Maximum acceptable concentrations in water where crustacea and the eggs and larva of salmonids develop are 0.003 mg/l in hard water and 0.0004 in soft water as defined above.

Rationale (Cadmium):

Cadmium is an extremely dangerous cumulative toxicant, causing insidious, progressive chronic poisoning in mammals (27), fish, and probably other animals because the metal is not excreted (See 1). The eggs and larvae of fish are apparently more sensitive than adult fish to poisoning by cadmium, and crustaceans are evidently more sensitive than fish eggs and larvae (See 1). The safe levels of cadmium for fathead minnows (28) and bluegills in hard water are between 0.06 and 0.03 mg/l, and safe levels for coho salmon fry have been reported between 0.004 to 0.001 mg/l in soft water (See 1). Concentrations of 0.0005 mg/l were observed to reduce reproduction of *Daphnia magna* in one generation exposures lasting three weeks (See 1).

b. Chromium

Maximum acceptable total chromium concentrations in water are 0.05 mg/l.

Rationale (Chromium):

The toxicity of chromium toward aquatic life varies widely with the species, temperature, pH, valence of the chromium and synergistic and antagonistic effects, particularly that of hardness (29). Recent data indicate that safe concentrations of hexavalent chromium in hard waters are 1.0 mg/l for fathead minnows, and in soft water 0.6 and 0.3 mg/l for brook and rainbow trout. Similar chronic no-effect levels for trivalent chromium were suggested by these data (see 1). Additional data revealed that some lower members of the food web are more sensitive to chromium than are fish. The reported lethal limits of hexavalent chromium for fish are 17 and 118 mg/l as compared to 0.05 mg/l for macroinvertebrates, and 0.032 to 6.4 mg/l for algae (1).

c. Copper

Maximum acceptable concentrations of copper (expressed as Cu) in water are 1/10 (0.10) of the 96-hour LC_{50} value determined using the receiving water in question and the most sensitive important species in the locality as the test organisms.

Rationale (Copper):

The toxicity of copper varies with the chemical characteristics of the water and with the species of test organism (29). Concentrations of 0.006 mg/l in soft water are thought to be safe for the reproduction and growth of *Daphnia magna* and fish, and in hard waters levels of 0.033 mg/l are apparently safe (See 1). Since safe to lethal ratios of copper in water vary from 0.1 to 0.2, an application factor of 0.1 of the 96-hour LC_{50} value should provide adequate protection for aquatic species (See 1).

d. Lead

Maximum acceptable concentrations of lead in water are 0.03 mg/l.

Rationale (Lead):

The toxicity of lead in water varies with its solubility which is a function of the hardness of the water. In soft waters lead has a solubility of 0.5 mg/l, whereas in hard water the solubility is only 0.003 mg/l (1). The effect of hardness upon the toxicity of lead was demonstrated by acute toxicity tests on several species of fish in waters of varying hardness. The 96-hour LC_{50} values in soft waters (20-45 mg/l $CaCO_3$) were 1.0 mg/l for rainbow trout (30), 4.0-5.0 mg/l for brook trout and 5.0-7.0 mg/l for fathead minnows (31, also see 1). In hard waters 96-hour LC_{50} values were 442 mg/l for brook trout and 482 mg/l for fathead minnows (31). Preliminary information on chronic toxicity of lead to rainbow and brook trout indicated detrimental effects at 0.10 mg/l in soft water (see 1). The growth of guppies was affected by 1.24 mg/l of lead (32), and concentrations of 0.1 and 0.3 mg/l caused chronic or sublethal effects on sticklebacks (33, 34). The safe level for Daphnia has been reported as 0.03 mg/1, and it has been suggested that this is also the safe level for fish (1).

e. Mercury (Inorganic)

1) Maximum acceptable total mercury concentration in unfiltered water at any time or place are 0.2 ug/l.

2) Maximum acceptable average mercury concentrations in unfiltered water are 0.05 ug/l.

3) Maximum acceptable concentrations of total mercury in any aquatic organism is a total body burden of 0.5 ug/g wet weight.

Rationale (Mercury - Inorganic):

The main body of available information is on organic compounds of mercury which are generally more dangerous to aquatic life and man. Since inorganic mercury is changed by organisms in nature to the organic forms the same limits are prescribed for both forms (see 1).

f. Nickel

Maximum acceptable concentrations of nickel in water are 1/50 (0.02) the 96-hour LC_{50} value determined using the receiving water in question and the most sensitive important species in the locality as the test organisms.

Rationale (Nickel):

Nickel as a pure metal does not constitute a serious water pollution problem; however, many of the salts of nickel are highly soluble in water and may present serious hazards to aquatic life (see 29). The 96-hour LC_{50} of nickel for fathead minnows ranges from 5 mg/l in soft water to 43 mg/l in hard water (see 31). Chronic safe concentrations for fathead minnows in hard water have been reported as varying between 0.8 and 0.4 mg/l, and in soft water levels of 0.030 mg/l had no effect on *Daphnia magna* during a 3-week exposure (see 1). Since the acute and chronic toxicity values of nickel vary widely, an application factor of 0.02 of the 96-hour LC_{50} is required to provide adequate protection for aquatic life.

q. Sulfides

Maximum acceptable concentrations of total sulfides in water are 0.002 mg/l.

Rationale (Sulfides):

Sulfides enter the water as constituents of many industrial wastes. The addition of soluble sulfides to water results in a reaction with hydrogen ions to form HS^- or H_2S, the proportion of each depending upon the pH of the water. Sulfides derive their toxicity from undissociated H_2S, which at a pH of 5 or 6 accounts for about 99 percent of the sulfides present in water. In neutral waters the sulfides appear in about equal proportion of HS^- and H_2S, and at a pH of 9 most of the sulfides are in the form of HS^- (1). Hydrogen sulfide may be formed by the microbial reduction of sulfates via sulfides (35) or from the decomposition of organic matter in sediments and sludge beds. Under low oxygen tensions or low pH, hydrogen sulfide may be present in concentrations which are toxic to aquatic life. Because most H_2S formation occurs at the mud-water interface, the invertebrates, fish eggs and fry may be seriously affected by H_2S production. Tabulated data on the toxicity of hydrogen sulfide to various fish species in all stages of development revealed 96-hour LC_{50} values ranging from 0.0018 to 0.071 mg/l and safe values ranging from 0.002 to 0.015 mg/l (1). The data suggest that fish eggs are the least sensitive and fry the most sensitive to H_2S exposure. Safe levels for the scud _Gammarus pseudolimnaeus_ and the mayfly, _Hexagenia limbata_, have been reported between 0.002 and 0.003 mg/l (36). Since sulfides in water readily combine with hydrogen to form toxic H_2S, limiting the total sulfide concentration in water to a maximum of 0.002 mg/l should provide adequate protection for the most sensitive species of aquatic life even if essentially all the sulfides present are in the form of H_2S.

h. _Zinc_

Maximum acceptable zinc concentrations in water are 5/1000 (0.005) the 96-hour LC_{50} value determined using the receiving water in question and the most sensitive important species in the locality as the test organisms.

Rationale (Zinc):

The acute lethal toxicity of zinc varies greatly with the hardness of the water, with the 96-hour LC_{50} for fathead minnows ranging from 0.87 mg/l in soft water to 33 mg/l in hard water (31). The lethal threshold also varies significantly between fish species, with bluegills more resistant than fathead minnows (1), and coarse fish more resistant than brook trout (37). Differences between acute and safe chronic concentrations of zinc on fathead minnows are great. In hard water, levels of 0.03 mg/l had no effect on fathead minnow reproduction, while 0.18 mg/l caused an 83 percent reduction in fecundity (38). Using a 96-hour LC_{50} of 9.2 mg/l, and the no-effect concentration of 0.03 mg/l yields a safe to lethal ratio of about 0.0033 (1). Owing to the great differences between the acute and safe concentration of zinc, an application factor of 5/1000 (0.005) of the 96-hour LC_{50} is required.

4. Organic Compounds

a. Cyanides

Maximum acceptable concentrations of free cyanides in water are 1/20 (0.05) the 96-hour LC_{50} value determined using the receiving water in question and the most sensitive important species in the area as test organisms in both static and flow-through bioassays. Maximum acceptable concentrations at any time or place are 0.005 mg/l.

Rationale (Cyanides):

Cyanides in water derive their toxicity primarily from undissociated hydrogen cyanide (HCN) rather than from the cyanide ion (CN^-) (39 - 42). HCN dissociates in water into H^+ and CN^- in a pH dependent reaction. At a pH of 7 or below, less than 1 percent of the cyanide is present as CN^-; at a pH of 8, 6.7 percent; at a pH of 9, 42 percent; and at a pH of 10, 87 percent of the cyanide is dissociated (43). Doudoroff (44) demonstrated more than a thousand fold increase in toxicity of a nickelocyanide complex associated with a decrease of pH from 8.0 to 6.5, and a pH change from

8.9 to 7.5 is said to increase the toxicity tenfold (2). The toxicity of cyanides is also increased by increases in temperature and reductions in oxygen tensions. A temperature rise of 10°C produced a two- to threefold increase in the rate of the lethal action of cyanide (46, 47). The median period of survival of trout at 17°C exposed to concentrations of 0.105 mg/l CN^- was reduced from 8 hours at 95 percent oxygen saturation to 10 minutes at 45 percent oxygen saturation (45). Most of the literature on the toxicity of cyanides and hydrogen cyanide expresses toxicity in terms of the cyanide ion. It was reported (48) that free cyanide concentrations from 0.05 to 0.01 mg/l as CN^- have proved fatal to many sensitive species. A level as low as 0.01 mg/l is know to have a pronounced, rapid, lasting effect on the swimming ability of salmon (1). Because safe HCN concentrations and acceptable LC_{50} application factors have not been positively demonstrated, conservative estimates of safe levels of cyanide in waters must be made. In determining acceptable cyanide levels for a given water body, both flow-through and static bioassays should be performed. Static bioassays may reveal much greater toxicity than the flow-through method because the partial dissociation of some complex metallocyanide ions may be slow. On the other hand volatile HCN may escape from standing cyanide solution exposed to the atmosphere in static bioassay containers.

b. Detergents

Maximum acceptable concentrations of linear alkylate sulfonates (LAS) in waters are 1/20 (0.05) the 96-hour LC_{50} value determined using the receiving water in question and the most sensitive important species in the area as test organisms. Concentrations of LAS in water in excess of 0.2 mg/l are unacceptable.

Rationale (Detergents):

The primary toxic component of detergents is the linear alkylate sulfonates (LAS) which since 1965 have been used by the detergent industry as a replacement for alkylbenzene sulfonates (ABS). LAS is more readily degradable biologically than ABS; however, it is also two to four times more toxic (49). Lethal concentrations of LAS to selected fish species have been found to vary from 0.2 to 10.0 mg/l in short term studies (50). Chronic toxicity studies revealed that 0.63 mg/l LAS had no measurable effect on the life cycle of the fathead minnow, while 1.2 mg/l were fatal to newly hatched fry (51). Investigations of the effects of LAS on invertebrates (52) indicated the no-effect level on *Gammarus pseudolimnaeus* to be 0.2 to 0.4 mg/l. The snails, *Physa integra* and *Campeloma decisum* exposed to LAS for 6 week periods were adversely affected by concentrations ranging from 0.4 to 4.4 mg/l.

c. Oils

If the following conditions are observed acceptable limits regarding the concentrations of oils in water will be achieved: a) There is no visible oil on the water surface; b) Concentrations of emulsified oils do not exceed 1/20 (0.05) of the 96-hour LC_{50} value determined using the receiving water in question and the most sensitive important species in the area; c) Concentrations of hexane extractable substances (exclusive of elemental sulfur) in air dried sediments do not exceed 1000 mg/kg on a dry weight basis.

Rationale (Oils):

Pollution resulting from oil spills or discharges may be in the form of floating oils, emulsified oils or solutions of the water soluble fractions of these oils (1). Floating oils may interfere with reaeration and photosynthesis and prevent respiration of aquatic insects which obtain their oxygen at the surface. Free and emulsified oils may act on the epithelial surface of fish gills interfering with respiration, or they may coat and destroy algae and other plankton. Sedimented oils may coat the bottom destroying benthic organisms and altering spawning areas. The water soluble fraction of oils may be very toxic to fish (53). Apparently the aromatic hydrocarbons are the major group of acutely toxic compounds in oil residues (54, 55). Owing to the wide range of results obtained in toxicity tests for oily substances, safe concentrations for all compounds cannot be accurately established. The 96-hour LC_{50} concentrations for various compounds range from 5.6 mg/l for nephenic acid to 14,500 mg/l for no. 2 cutting oil (see 1). There is evidence that oils may persist and have subtle chronic effects (54). Because of the difficulties in establishing safe levels, the maximum allowable concentrations can only be determined on a case-by-case basis using bioassay procedures.

d. Phthalate Esters

Maximum acceptable concentrations of phthalate esters in water are 0.3 ug/l.

Rationale (Phthalate Esters):

Phthalate ester residues have been found in various segments of the aquatic environment of North America. Principal occurrences, however, have been reported from industrial and heavily populated areas (56). In acute toxicity tests the 96-hour LC_{50} of di-n-butyl phthalate to four species of fish and *Daphnia magna* ranged between 731 and 6470 ug/l (see 1). Chronic toxicity tests have shown the substance to be highly cumulative, with a concentration factor of 6,000 reported for *Daphnia magna* during a ten-day exposure (see 1). However, after transfer of the organism to uncontaminated water, approximately 50 percent of the residue was excreted in three days (1). Concentrations of 3 ug/l of di-2-ethylhexyl phthalate have been shown to significantly reduce the growth and reproduction of Daphnia magna (see 1).

e. Organic Mercury

Maximum acceptable total mercury concentrations in water are 0.2 ug/l and the maximum average total mercury concentrations are 0.05 ug/l. The maximum acceptable concentration of total mercury in any aquatic organism is a total body burden of 0.5 ug/g wet weight.

Rationale (Organic Mercury):

Mercury is a dangerous, cumulative toxicant which enters the bodies of aquatic organisms directly from the water and through the food chain (57 - 60). Although methylmercury is the form of mercury of primary concern as regards toxicity, the ability of certain microbes to synthesize methylmercury from the inorganic form, renders all mercury in waterways potentially dangerous. The incident at Minemata, Japan, during the 1950's in which several human deaths resulted from the consumption of mercury contaminated fish and shellfish focused attention upon the hazards of mercury poisoning to humans. Since mercury is biologically concentrated through the food web, levels of protection in the aquatic environment must be such that final consumers, including man, are afforded adequate protection. Freshwater phytoplankton, macrophytes and fish are capable of biologically magnifying mercury concentrations from water 1,000 times (61). Concentration factors of 5,000 from water to pike have been reported (57), and factors of 10,000 or more have been reported from water to brook trout (see 1) and to some invertebrates (58). The chronic effects of mercury upon reproduction and growth of fish are not well known. The lowest levels which have resulted in the death of fish are 0.2 ug/l, which killed fathead minnows exposed for 6 weeks (see 1). Levels of 0.1 ug/l decreased photosynthesis and growth of marine algae and some freshwater phytoplankton (62). Exposure of fish for a period of three months to concentrations of 0.05 ug/l of mercury in water resulted in concentrations of 0.5 ug/g in the fish (1). This is the maximum Food and Drug Administration guideline level for edible portions. In an effort to maintain mercury concentrations in fish below 0.5 ug/g the limits established above must be observed.

f. Polychlorinated Biphenyls (PCB's)

Maximum acceptable concentrations of PCB's in water are 0.002 ug/l, and maximum acceptable levels of residues in general body tissues of any aquatic organism are 0.5 ug/g.

Rationale (Polychlorinated Biphenyls):

PCB residue levels of 0.5 mg/l in whole salmon eggs have been suggested as the threshold for egg mortality (63). Such levels in eggs are associated with levels in the body tissue of 2.5 to 5.0 ug/g (1). PCB's are highly cumulative with accumulation factors of up to 200,000 indicated by long term exposure of fish to low PCB concentrations in water (1). Consequently, in order to provide adequate protection for egg development, and to provide an adequate safety factor to protect against excessive accumulations in tissue, the 0.002 ug/l maximum concentration limit in waters shall be observed.

g. Phenolic Compounds

Maximum acceptable concentrations of phenolic compounds in water are 1/20 of the 96-hour LC$_{50}$ determined using the most sensitive important species as a test organism. Concentrations in excess of 0.1 mg/l are unacceptable.

Rationale (Phenolic Compounds):

Phenols and phenolic wastes are derived from petroleum, coke, and chemical industries; wood distillation; and domestic and animal wastes. Many phenolic compounds are more toxic than pure phenol: their toxicity varies with the combinations and general nature of total wastes. Acute toxicity of pure phenol varies between 0.079 mg/l in 30 minutes to minnows, and 56.0 mg/l in 96 hours to mosquito fish (*Gambusia affinis*). A 48-hour LC$_{50}$ of 7.5 mg/l has been reported for trout; also exposures to 6.5 mg/l caused damage to epithelial cells in 2 hours, and extensive damage to reproductive systems in 7 days. A level of 1.0 mg/l is safe to trout; and 0.10 mg/l was found non-lethal to bluegill (*Lepomis macrochirus*) in 48 hours (see 1). These studies illustrated the wide range of phenol toxicity.

There is not yet adequate documentation about chronic effects and toxicity of mixed wastes on which to base recommendations of safe levels for fish. Phenolics affect the taste of fish at levels that do not appear to affect fish physiology adversely. Mixed wastes often have more objectionable effects than pure materials. For example, 2.4-dichlorphenol affects taste at 0.001 - 0.005 mg/l; p-chlorophenol at 0.01 - 0.06 mg/l; and 1-methyl, 6-chlorophenol at 0.003 mg/l. Pure phenol did not affect taste until levels of 1 - 10 mg/l were reached. The taste of fish in polluted situations is adversely affected by phenolics before acute effects are observed (see 1).

5. Pesticides

a. General

For pesticides on which toxicity data are not available, maximum acceptable concentrations in water are 1/100 (0.01) of the 96-hour LC_{50} value determined using the receiving water in question and the most sensitive important species in the area as test organisms.

b. Organochlorines

The maximum acceptable concentrations of organochlorine pesticides in water are listed in Table 1.

c. Other Pesticides

The maximum acceptable concentrations of pesticides other than organochlorines in fresh water are listed in Table 2.

Rationale (Pesticides):

The permissible maximum pesticide concentrations in water are based upon acute toxicity values for the most sensitive species of aquatic life. For permissible instantaneous maximum concentration, an application factor of 1/20 (0.05) of the 96-hour LC_{50} values was applied. The maximum permissible 24-hour average concentrations were derived by applying an application factor of 1/100 (0.01) to the 96-hour LC_{50} value.

Pesticides

TABLE 1*

Recommended Maximum Concentrations of Organochlorine Pesticides in Whole (Unfiltered) Water Sampled at any Time and Any Place. a/

Organochlorine pesticides	Permissible maximum concentration (ug/l)
Aldrin	0.01
DDT	0.002
TDE	0.006
Dieldrin	0.005
Chlordane	0.04
Endosulfan	0.003
Endrin	0.002
Heptachlor	0.01
Lindane	0.02
Methoxychlor	0.005
Toxaphene	0.01

a/ Concentrations were determined by multiplying the acute toxicity values for the more sensitive species by an application factor of 0.01.

* Source: (1)

TABLE 2*

Recommended Maximum Concentrations of other Pesticides in Whole (Unfiltered) Water Sampled at any Time and any Place. a/

Organophosphate insecticides	Permissible maximum concentration (ug/l)
Abate	(b)
Azinphosmethyl	0.001
Azinphosethyl	(b)
Garbophenothion	(b)
Chlorothion	(b)
Ciodrin	0.1
Coumaphos	0.001
Demeton	(b)
Diazinon	0.009
Dichlorvos	0.001
Dioxathion	0.09
Disulfonton	0.05
Dursban	0.001
Ethion	0.02
EPN	0.06
Fenthion	0.006
Malathion	0.008
Methyl Parathion	(b)
Mevinphos	0.002
Naled	0.004
Oxydemeton Methyl	0.4
Parathion	0.001
Phorate	(b)
Phosphamidon	0.03
Ronnel	(b)
TEPP	0.3
Trichlorophon	0.002

a/ Concentrations were determined by multiplying the acute toxicity values for the more sensitive species by an application factor of 0.01.

b/ Insufficient data to determine safe concentrations.

* Source: (1)

TABLE 2 (Cont.)*

Carbamate Insecticides	Permissible maximum Concentrations (ug/l)
Aminocarb	(b)
Bayer	(b)
Baygon	(b)
Carbaryl	0.02
Zectran	0.1

a/ Concentrations were determined by multiplying the acute toxicity values for the more sensitive species by an application factor of 0.01.

b/ Insufficient data to determine safe concentrations.

* Source: (1)

TABLE 2 (Cont.)*

Herbicides, Fungicides and Defoliants	Permissible maximum Concentration (ug/l)
Acrolein	(b)
Aminotriazole	300.0
Balan	(b)
Bensulfide	(b)
Choroxuron	(b)
CIPC	(b)
Dacthal	(b)
Dalapon	110.0
DEF	(b)
Dexon	(b)
Dicamba	0.2
Dichlobenil	37.0
Dichlone	0.7
Diquat	0.5
Diuron	1.6
Difolitan	(b)
Dinitrobutyl Phenol	(b)
Diphenamid	(b)
2-4,D (PGBE)	(b)
2-4,D (BEE)	4.0
2-4,D (IOE)	(b)
2-4,D (Diethylamine salts)	(b)
Endothal (Disodium salt)	(b)
Endothal (Dipotassium salt)	(b)
Eptam	(b)
Fenac (Sodium salt)	45.0
Hyamine-1622	(b)
Hyamine-2389	(b)
Hydrothal-47	(b)
Hydrothal-191	(b)
Hydrothal plus	(b)

a/ Concentrations were determined by multiplying the acute toxicity values for the more sensitive species by an application factor of 0.01.

b/ Insufficient data to determine safe concentrations.

* Source: (1)

TABLE 2 (cont.)*

Herbicides, Fungicides and Defoliants	Permissible maximum Concentration (ug/l)
IPC	(b)
MCPA	(b)
Molinate	(b)
Monuron	(b)
Paraquat	(b)
Pebulate	(b)
Picloram	(b)
Propanil	(b)
Silvex (BEE)	2.5
Silvex (PGBE)	2.0
Silvex (IOE)	(b)
Silvex (Potassium salt)	(b)
Simazine	10.0
Trifluaralin	(b)
Vernolate	(b)

Botanicals	Permissible maximum concentration (ug/l)
Allethrin	0.002
Pyrethrum	0.01
Rotenone	10.0

a/ Concentrations were determined by multiplying the acute toxicity values for the more sensitive species by an application factor of 0.01.

b/ Insufficient data to determine safe concentrations.

* Source: (1)

6. Physical (Except Temperature)

a. Color

Acceptable conditions regarding the combined effect of color and turbidity in water will be met if the compensation point is not changed by more than 10 percent from its seasonally established norm, and if no more than 10 percent of the biomass of photosynthetic organisms is placed below the compensation point by such changes.

See also turbidity, settleable and suspended solids.

Rationale (Color):

True water color is a result of substances in solution after the suspended materials have been removed. Color may be derived from mineral or organic sources and may be the result of natural processes as well as manufacturing operations. Organic sources such as humic materials, peat, plankton, aquatic plants and tannins impart color to water. Inorganic sources include metallic substances, chemicals and dyes. The effect of water color upon aquatic life is to limit light penetration, thereby restricting the depth of the photosynthetic zone and impacting upon the benthos. The light intensity at which photosynthetic oxygen production equals the amount of oxygen consumed through respiration is known as the compensation point, and the depth at which this occurs is the compensation depth (64). As commonly used, the compensation point refers to that intensity of light which is such that the plant's oxygen production during the day will be sufficient to balance the oxygen consumption during the whole 24-hour period (1).

b. Turbidity

Acceptable conditions regarding the combined effect of color and turbidity in water will be met if the compensation point is not changed by more than 10 percent from its seasonally established norm, and if no more than 10 percent of the biomass of photosynthetic organisms is placed below the compensation point by such changes.

See also color, settleable and suspended solids.

Rationale (Turbidity):

The light intensity at which photosynthetic oxygen production equals the amount of oxygen consumed through respiration is known as the compensation point, and the depth at which this occurs is the compensation depth (64). As commonly used, the compensation point refers to that intensity of light which is such that photosynthetic oxygen production during the day will be sufficient to balance the oxygen consumption during the whole 24-hour period (1). Turbidity results from the presence of suspended matter such as sand, clay, silt, finely divided organic matter, plankton and bacteria (2). Agricultural runoff, construction activities, industrial operations, storm sewers and municipal wastes are man induced sources which contribute to turbidity. The inhibition of light penetration by suspended matter not only restricts the zone of primary production, but influences the temperature patterns as well. Heat is absorbed rapidly near the surface in turbid waters, thus creating density stratification which may interfere with vertical mixing and heat and oxygen transfer. Finely divided suspended solids may impact upon the fisheries of a river or lake by various means. These include killing the fish directly, inhibiting growth or egg and larvae development, interfering with natural movements, reducing the availability of food, and reducing the fish's ability to capture food organisms (65).

7. Radioactivity

The acceptable levels of radionuclides in fresh water inhabited by plants and animals are those concentrations which are sufficiently small that any (bioconcentrating) organisms harvested for human consumption will not cause total radionuclide ingestion by the most exposed group using the food to exceed those limits prescribed in Federal Drinking Water Standards. If the consumption of these foodstuffs is so widespread that it is likely that the aggregate dose to the exposed population will exceed 3000 man-rem per year, limitations on the distribution and sale should be considered by the relevant public health authorities.

Rationale (Radioactivity):

These criteria are based on the prudent assumption that radiation levels which are acceptable for human food consumption will not injure fresh water aquatic life. When radioactive materials enter surface waters they are diluted and dispersed by the same forces acting on other soluble or suspended materials (99). When first introduced into surface waters a substantial part of materials present in radioactive wastes becomes associated with suspended organic and inorganic particulates that settle to the bottom, and many radioisotopes are eventually bound chemically to the sediments. Radioisotopes are passed through the various trophic levels of the food chain and are either bioconcentrated or released depending upon the prey-predator organisms, physical and chemical state of the radionuclide, and the equilibrium conditions (100). The concentration of a radioisotope by an organism is expressed in terms of the ratio of its concentration in the organism to that in the surrounding water or preceding link in the food chain. Possible effects to the individual organism may include death, inhibition or stimulation of growth, physiological change, changes in behavioral patterns, developmental abnormalities, or shortening of life span. At one time, it was widely believed that there was a no-damage radiation threshold, but the consensus of most radiation biologists today is that any increase over background will have some biological effect (a linear, non-threshold theory). While some genetic changes are reported to be the result of primordial radioisotopes and cosmic rays, these changes usually constitute less than one percent of all spontaneously occurring mutations (99). A vast amount of research on dose effect relationships of warm-blooded animals has led to recommendations on human radiation exposure. Compared with these data only a meager amount of information is available on chronic dose-effect relationships for aquatic forms. Since wild species suffering radiation induced genetic damage are often removed by natural selection or eaten by predators, aquatic organisms affected by radiation are not readily recognized in the field. The natural populations of fish that have probably sustained the greatest exposure to man-made radioactive materials are those found near major atomic energy installations. However, stocks of plaice in the vicinity of the Windscale outfall have been unaffected (102) by doses of about 10 rads per year. Columbia River salmon spawning in the vicinity of Hanford outfalls are reported (103) to have been unaffected by doses in the range of 5 to 10 rads per year. While these observations on chronic exposure of aquatic organisms provide a subjective assessment of radiation sensitivities in natural populations, they are not sufficiently definitive to form the basis for additional water quality criteria aimed at the specific protection of aquatic life. However, these observations do suggest that even under conditions of significant radionuclide concentration in the effluent, the aquatic life is not injured.

8. Solids

a. Total Dissolved Solids and Hardness

Concentrations of total dissolved materials should not be changed to the extent that the biological communities characteristic of particular habitats are significantly changed. When dissolved materials are altered, bioassays and field studies should be conducted to determine the limits that may be tolerated without endangering the structure and function of the aquatic ecosystem.

Rationale (Total Dissolved Solids and Hardness):

Total dissolved solids is the general term describing the concentrations of dissolved materials in water. The more conspicuous constituents of total dissolved solids in natural surface water include the carbonates, sulfates, chlorides, phosphates, and nitrates. These anions occur in combination with such metallic cations as calcium, sodium, potassium, magnesium, and iron to form ionizable salts (2). The quantity and quality of dissolved solids are major factors determining the variety and abundance of plant and animal life in an aquatic system. They serve as nutrients in productivity and as agents in osmotic stress and direct toxicity. Major changes in quantity or composition of total dissolved solids have the effect of causing attendant changes in the structure and function of aquatic ecosystems (1). Hardness of surface waters is a component of total dissolved solids and is chiefly attributable to calcium and magnesium ions. Other ions such as iron, copper, zinc, lead, manganese, boron, and strontium also contribute to total hardness, but the effect is usually minimal since these are ordinarily present in only trace amounts. Generally, the biological productivity of water is correlated with the hardness, but the hardness *per se* has no biological significance because biological effects are a function of the specific concentration and combination of the elements present. The term "hardness" serves a useful purpose as a general index of water type, buffering capacity and productivity, but it should be avoided in determining water quality requirements for aquatic life. More emphasis should be placed on specific ions (1).

b. Suspended and Settleable Solids

Maximum acceptable total concentrations of suspended solids in fresh water are 80 mg/l.

Acceptable conditions regarding the combined effect of color and turbidity in water will generally be met if the compensation point is not changed by more than 10 percent from its seasonally established norm, and if no more than 10 percent of the biomass of photosynthetic organisms is placed below the compensation point by such changes.

See also color and turbidity.

Rationale (Suspended and Settleable Solids):

Suspended and settleable solids include such materials as sand, clay, finely divided organic material, bacteria and plankton (2). Agricultural runoff, construction activities, industrial operations, storm sewers and municipal wastes are the principal sources which contribute suspended and settleable solids. The suspended and settleable solids and the bed of a water body must be considered as interrelated, interacting parts.

Concentrations of suspended matter in water are found to change rapidly with wind intensity and rainfall. The composition and concentrations of suspended particles in surface waters are important because of their effect on light penetration, temperature, solubility products and aquatic life. The abrasive action of particulate material affects fish and other aquatic organisms. Settleable solids blanket animals, plants and their habitats, either killing the organism or rendering the habitats unsuitable for occupation. Suspended particles also serve as a transport mechanism for pesticides and other toxic substances which are readily sorbed into or onto clay particles. It is reported (65) that there is no evidence that concentrations of suspended solids less than 25 mg/l have any harmful effects on fisheries. Waters containing concentrations of 25 to 80 mg/l should be capable of supporting good to moderate fisheries, whereas waters with concentrations in excess of 80 mg/l are unlikely to support good freshwater fisheries (65).

9. Tainting Substances

Substances which cause tainting of fish and other aquatic organisms are unacceptable in water in concentrations which lower the acceptability of such organisms as determined by bioassay and organoleptic tests. The values in Tables 3 and 4 serve as guidelines in determining what concentrations of substances in water may cause tainting of fish and other aquatic organisms.

Rationale (Tainting Substances):

Discharges from municipal waste water treatment plants, a variety of industrial wastes and organic compounds, as well as certain organisms can impart objectionable taste, odor or color to the flesh of fish and other edible organisms. Such tainting can occur in waters with concentrations of the offending material lower than those recognized as being harmful to an animal. See Tables 3 and 4.

TABLE 3

Wastewaters Found to Have Lowered the Palatability of Fish Flesh

Wastewater Source	Concentration in Water Affecting Palatability of Fish	Species
2,4-D mfg. plant	50 - 100 mg/l	Trout
Coal - coking	0.02 - 0.1 mg/l	Freshwater fish
Coal - tar	0.1 mg/l	Freshwater fish
Kraft process (untreated)	1 - 2% by vol.	Salmon
Kraft process (treated)	9 - 12% by vol.	Salmon
Kraft and neutral sulfite process	----	Trout
Municipal dump runoff	----	Channel catfish (*Ictalurus punctatus*)
Municipal untreated sewage (2 locations)	----	Channel catfish
Municipal wastewater (4 locations)	----	Channel catfish
Municipal wastewater treatment plant (primary)	11 - 13% by vol.	Freshwater fish
Municipal wastewater treatment plant (secondary)	20 - 26% by vol.	Freshwater fish
Oily wastes	----	Trout
Refinery	----	Trout
Sewage containing phenols	0.1 mg/l	Freshwater fish
Slaughterhouses (2 locations)	----	Channel catfish

Source: (1)

TABLE 4

Concentrations of Chemical Compounds in Water That Can Cause Tainting of the Flesh of Fish and Other Aquatic Organisms*

Chemical	Estimated threshold level in water (mg/l)
acetophenone	0.5
acrylonitrile	18
cresol	0.07
m-cresol	0.2
o-cresol	0.4
p-cresol	0.12
cresylic acid (meta para)	0.2
N-butylmercaptan	0.06
o-sec. butylphenol	0.3
p-tert. butylphenol	0.03
o-chlorophenol	0.0001 to 0.015
p-chlorophenol	0.01 to 0.05
2,3-dichlorophenol	0.084
2,4-dichlorophenol	0.001 to 0.014
2,5-dichlorophenol	0.023
2,6-dichlorophenol	0.035
2,methyl, 4-chlorophenol	0.075
2,methyl, 6-chlorophenol	0.003
o-phenylphenol	1
2,4,6-trichlorophenol	0.003 to 0.05
phenol	1 to 10
phenols in polluted river	0.02 to 0.15
diphenyl oxide	0.05
, -dichlorodiethyl ether	0.09 - 1.0
o-dichlorobenzene	0.25
ethylbenzene	0.25
ethanethiol	0.24
ethylacrylate	0.6
formaldehyde	95
kerosene	0.1
kerosene plus kaolin	1
isopropylbenzene	0.25
naphtha	0.1
naphthalene	1
naphthol	0.5
2-naphthol	0.3
dimethylamine	7
-methylstyrene	0.25
oil, emulsifiable	15
pyridine	5 to 28
pyrocatechol	0.8 to 5
pyragallol	20 to 30
quinoline	0.5 to 1
p-quinone	0.5
styrene	0.25
toluene	0.25
outboard motor fuel, as exhaust	2.6 gal/acre-foot
guaiacol	0.082

* Source: (1)

10. Temperature

Acceptable temperature limits in fresh water during any time of the year are:

a. A maximum weekly average temperature that:

1. In receiving waters during the warmer months (i.e., April through October in the North and March through November in the South) is one third of the range between the optimum temperature and the ultimate upper incipient lethal temperature for the most sensitive important species (or appropriate life stage) that is normally found at the location at that time;

2. In the heated plume during the cooler months (i.e., mid-October to mid-April in the North and December to February in the South) corresponds to the appropriate ambient temperature in the nomograph in Figure 1. in the North and December to February in the South) is that elevated temperature from which important species die when that elevated temperature is suddenly dropped to the normal ambient temperature, with the limit being the acclimation temperature (minus a 2°C safety factor), when

the lower incipient lethal temperature equals the normal ambient water temperature (in some regions this limit may also be applicable in summer);

3. During reproduction seasons (generally April-June and September-October in the North and March-May and October-November in the South) meets specific site requirements for successful migration, spawning, egg incubation, fry rearing, and other reproductive functions of important species as presented in Table 6.

or 4. At a specific site is found necessary to preserve normal species diversity or prevent undesirable growth of nuisance organisms.

and b. maximum temperature for short-term summer and spawning exposures as developed using the resistance time equation:

$$\log \text{time} = a + b(\text{Temp.})$$

where a and b respectively are intercept and slope, which are characteristics of each acclimation temperature for each species.

Local requirements for reproduction should supersede all other requirements when they are applicable. Detailed ecological analysis of both natural and man-modified aquatic environments is necessary to ascertain when these requirements should apply. Available data for temperature requirements for growth and reproduction, lethal limits for various acclimation temperature levels, and various temperature-related characteristics of many of the more important freshwater fish species are included in Appendix A.

Rationale (Temperature):

Living organisms do not respond to the quantity of heat; instead, to degrees of temperature or to temperature changes caused by transfer of heat. Organisms have upper and lower thermal tolerance limits, optimum temperatures for growth, preferred temperatures in thermal gradients, and temperature limitations for migration, spawning, and egg incubation; temperature also affects the physical environment of the aquatic medium (e.g., viscosity, degree of ice cover, and oxygen capacity); therefore, the composition of aquatic communities depends largely on temperature characteristics of the environment. Because temperature changes may affect the composition of an aquatic community, an induced change in the thermal characteristics of an ecosystem may be detrimental. On the other hand, altered thermal characteristics may be beneficial, as evidenced in some of the newer fish hatchery practices and at other aquacultural facilities. The general difficulty in developing suitable criteria for temperature (which would limit the addition of heat) is to determine the deviation from "natural" temperature a particular body of water can experience without adversely affecting its desired biota. Whatever requirements are suggested, a natural seasonal cycle must be retained, annual spring and fall changes in temperature must be gradual, and large unnatural day-to-day fluctuations should be avoided. In view of the many variables, it seems obvious that no single temperature requirement can be applied uniformly to continental or large regional areas; the requirements must be closely related to each body of water and to its particular community of organisms, especially the important species found in it. These should include invertebrates, plankton, or other plant and animal life that may be of importance to food chains or otherwise interact with species of direct interest to man. Since thermal requirements of various species differ, the social choice of the species to be protected allows for different "levels of protection" among water bodies. Although such decisions clearly transcend the scientific judgments needed in establishing thermal criteria for protecting selected species, biologists can aid in making these decisions. Some measures useful in assigning levels of "importance" to species are: (1) high yield or desirability to commercial or sport fisheries, (2) large biomass in the existing ecosystem (if desirable), (3) important links in food chains of other species judged important for other reasons, and (4) "endangered" or unique status. If it is desirable to attempt strict preservation of an existing ecosystem, then the most sensitive species or life stage may dictate the criteria selected. Criteria for making recommendations for water temperature to protect desirable aquatic life cannot be simply a maximum allowed change from natural temperatures. This is principally because a change of even one degree from an ambient temperature has varying significance for an organism, depending upon where the ambient level lies within the tolerance range. In addition, historic temperature records or, alternatively, the existing ambient temperature prior to any thermal alterations by man are not always reliable indicators of desirable conditions for aquatic populations. Multiple developments of water resources also change water temperatures both upward (e.g., upstream power plants or shallow reservoirs) and downward (e.g., deepwater releases for large reservoirs) so that ambient and natural temperatures at a given point can best be defined only on a statistical basis. Criteria for temperature should consider both the multiple thermal requirements of aquatic species and requirements for balanced communities. The number of distinct requirements and the necessary values for each require periodic re-examination as knowledge of thermal effects on aquatic species and communities increases. Currently definable requirements include:

- maximum sustained temperatures that are consistent with maintaining desirable levels of productivity (growth minus mortality);

- maximum levels of thermal acclimation that will permit return to ambient winter temperatures should artificial sources of heat cease;

- temperature limitations for survival of brief exposures to temperature extremes, both upper and lower;

. restricted temperature ranges for various stages of reproduction, including (for fish) gonad growth and gamete maturation, spawning migration, release of gametes, development of the embryo, commencement of independent feeding (and other activities) by juveniles; and temperatures required for metamorphosis, emergence, and other activities of lower forms;

thermal limits for diverse compositions or species of aquatic communities, particularly where reduction in diversity creates nuisance growths of certain organisms, or where important food sources or chains are altered;

. thermal requirements of downstream aquatic life where upstream warming of cold water sources will adversely affect downstream temperature requirements.

Thermal criteria must also be formulated with knowledge of how man alters temperatures, the hydrodynamics of the changes, and how the biota can reasonably be expected to interact with the thermal regimes produced. It is not sufficient, for example, to define only the thermal criteria for sustained production of a species in open waters, because large numbers of organisms may also be exposed to thermal changes by being pumped through the condensers and mixing zone of a power plant. Design engineers need particularly to know the biological limitations to their design options in such instances. Considerations such as impingement of fish upon intake screens, mechanical or chemical damage to zooplankton in condensers, or effects of altered current patterns on bottom fauna in a discharge area may reveal non-thermal impacts of cooling processes that may outweigh temperature effects. The environmental situations of aquatic organisms (e.g., where they are, when they are there, in what numbers) must also be understood. Thermal criteria for migratory species should be applied to a certain area only when the species is actually there. Although thermal effects of power stations are currently of great interest, other less dramatic causes of temperature change including deforestation, stream channelization, and impoundment of flowing water must be recognized. Available data for temperature requirements for growth and reproduction, lethal limits for various acclimation temperature levels, and various temperature-related characteristics of many of the more desirable freshwater fish species are included in the Appendix. General temperature criteria for these species are summarized in Tables 5 and 6. Some basic thermal response of aquatic organisms will be referred to repeatedly and are defined and reviewed briefly here. Effects of heat on organisms and aquatic communities have been reviewed periodically (e.g., 66, 67, 68, 69, 70, 71). Some effects have been analyzed in the context of thermal modification by power plants (72, 73, 74, 75, 76). Bibliographic information is available in various publications (77, 78, 79, 80, 81, 82). The thermal tolerance range is adjusted upward by acclimation to warmer water and downward by cooler water, although there is a limit to such accommodation. The lower end of the range usually is at zero degrees centigrade (32° F) for species in temperate latitudes (somewhat less for saline waters), while the upper end terminates in an "ultimate incipient lethal temperature" (83). This ultimate threshold temperature represents the "breaking point" between the highest temperatures to which an animal can be acclimated and the lowest of the temperatures that will kill the warm-acclimated organism. At the temperatures above and below the incipient lethal temperatures, survival depends not only on the absolute temperature but also on the duration of exposure, with mortality occurring more rapidly the higher the temperature is above the threshold. Because the equations based on research on thermal tolerance predict 50 percent mortality, a safety factor is needed to assure no mortality. Several studies have indicated that a two degree (centigrade) reduction of an upper lethal temperature results in no mortalities within an equivalent exposure duration (84, 85). The validity of a two degree safety factor was strengthened by the results of Coutant (81), which showed that for median mortality at a given high temperature, for about 15 to 20 percent of the exposure time there was induced selective predation on thermally shocked salmon and trout. This also amounted to reduction of the effective stress temperature by about two degrees centigrade. Unpublished data from subsequent predation experiments showed that this reduction of about two degrees centigrade also applied to the incipient lethal temperature. The level at which there is no increased vulnerability to predation is the best estimate of no-stress exposure that is currently available. Occupancy of habitats by most aquatic organisms often is limited within the thermal tolerance range to temperatures somewhat below the ultimate upper incipient lethal temperature. This is the result of poor physiological performance at near lethal temperatures (e.g., growth, metabolic scope for activities, appetite, food conversion efficiency), interspecies competition, disease, predation, and other subtle ecological factors. This complex limitation is evidenced by restricted southern and altitudinal distributions of many species. On the other hand, optimum temperatures (such as those producing fastest growth rates) are not generally necessary at all times to maintain thriving populations and are often exceeded in nature during summer months. Moderate temperature fluctuations can generally be tolerated as long as a summer maximum upper limit is not exceeded for long periods. A true temperature limit for exposures long enough to reflect metabolic acclimation and optimum ecological performance must lie somewhere between the physiological optimum and the ultimate upper incipient lethal temperature. Examination of literature on physiological optima (swimming, metabolic rate, temperature preference, growth, natural distribution, and tolerance) of several species has yielded an apparently sound theoretical basis for estimating an upper temperature limit for long term exposure. The most sensitive function for which data are available appears to be growth rate. A temperature that is one-third of the range between the optimum temperature for growth and the ultimate incipient lethal temperature can be calculated by the formula

$$\text{Optimum temp for growth} + \frac{\text{Ultimate incipient lethal temp} - \text{optimum temp for growth}}{3}$$

This formula offers a practical method for obtaining allowable limits, while retaining as its scientific basis the requirements of preserving adequate rates of growth. This formula was used to calculate the summer growth criteria in Table 5. The criterion for a specific location would be determined by the most sensitive life stage of an important species likely to be present in that location at that time. Since many fishes have restricted habitats (e.g., specific depth zones) at many life stages, the thermal criterion must be applied to the proper zone. There is field evidence that fish avoid localized areas of unfavorably warm water. This has been demonstrated both in lakes where coldwater fish normally evacuate warm shallows in summer and at power station heated plumes. In most large bodies of water there are both vertical and horizontal thermal gradients that mobile organisms can follow to avoid unfavorable high (or low) temperatures. The summer maxima must apply to restricted local habitats such as lake hypolimnia or thermoclines, that provide important summer sanctuary areas for coldwater species. Any avoidance of a warm area not part of the normal seasonal habitat of the species will mean that less area of the water body is available to support the population and that production may be reduced. Such reduction should not interfere with biological communities or populations of important species to a degree which is damaging to the ecosystem or other beneficial uses. Non-mobile organisms that must remain in the warm zone will probably be the limiting organisms for that location. Any upper limiting temperature criteria must be applied carefully with understanding of the population dynamics of the species in question in order to establish both local and regional requirements. Although artificially produced temperature elevations during winter months may actually bring the temperature closer to optimum or preferred temperature for important species, and attract fish, metabolic acclimation to these higher levels can preclude safe return of the organism to ambient temperatures should the artificial heating suddenly cease or the organism be driven from the heated area. The lower limit of the range of thermal tolerance of important species must, therefore, be maintained at the normal seasonal ambient temperatures throughout cold seasons. This can be accomplished by limitations on temperature elevations in such areas as discharge canals and mixing zones where organisms may reside, or by insuring that maximum temperatures occur only in areas not accessible to important aquatic life for lengths of time sufficient to allow metabolic acclimation. Such inaccessible areas would include the high-velocity zones of diffusers or screened discharge channels. This reduction of maximum temperatures would not preclude use of slightly warmed areas as sites for intense winter fisheries. This consideration may be important in some regions at times other than in winter. The Great Lakes, for example, are susceptible to rapid changes in elevation of the thermocline in summer which may induce rapid decreases in shoreline temperatures (upwelling). Fish acclimated to exceptionally high temperatures in discharge canals may be killed or severely stressed without changes in power plant operations. Some numerical values for acclimation temperatures and lower limits of tolerance ranges (lower incipient lethal temperatures) for several species are given in Appendix A. For some species such as yellow perch and lake whitefish lower winter temperature is necessary to ensure acceptable egg maturation prior to spawning. Figure 1 is a nomograph that demonstrates the relationship between the maximum weekly average temperature acceptable in heated plumes and different ambient temperatures. The nomograph was calculated on the line of lower incipient lethal temperature data that would, after applying the 2°C safety factor, ensure protection against partial lethality for most fish species for which there are data (1). At an acclimation (heated plume) temperature of 10°C (50°F) or less warm water fishes can tolerate a drop in temperature to any lower ambient temperature. This means (see Fig. 1) that whenever the ambient temperature is less than 2.5°C (37°F), the heated plume may be as warm as 10°C (50°F). However, trout and salmon cannot withstand comparable temperature declines and the nomograph should be used down to an ambient temperature of 0°C (32°F). At this temperature a maximum plume temperature of 5°C (41°F) is permissible. The maximum weekly average temperatures during the winter months are applicable to the heated plume rather than the receiving water since the principal concern for most fish at that time is to protect against excessive rapid decline in temperature. At the time that the earliest spawning should occur, the appropriate maximum weekly average temperature for the receiving water must be applied again. If species similar to yellow perch or lake whitefish are to be protected a maximum weekly average temperature in the receiving water during the winters would be necessary as well as the limitation in the plumes. To protect aquatic life and yet allow other uses of the water, it is essential to know the lengths of time organisms can survive extreme temperatures (i.e., temperatures that exceed the 7-day incipient lethal temperature). The length of time that 50 percent of a population will survive temperature above the incipient lethal temperature can be calculated from a regression equation of experimental data as follows:

$$\log \text{time}_{(\text{min})} = a + b\,(\text{Temp.})_{(^{\circ}\text{C})}$$

where a and b are intercept and slope, respectively, which are characteristics of each acclimation temperature for each species. In some cases the time-temperature relationship is more complex than the semilogarithmic model given above. This equation, however, is the most applicable, and is generally accepted by the scientific community (70). Caution is recommended in extrapolating beyond the data limits of the original research. Thermal resistance may be diminished by the simultaneous presence of toxicants or other debilitating factors. The most accurate predictability can be derived from data collected using water from the site under evaluation. It is clear that adequate data are available for only a small percentage of aquatic species, and additional research is necessary. Thermal resistance information should be obtained locally for critical areas to account for simultaneous presence of toxicants or other debilitating factors, a consideration not reflected in the Appendix data. The resistance time equation discussed earlier was used to calculate tolerance limits for many species of fish for several time intervals up to 10,000 minutes. The results of these calculations revealed a uniform relationship between these species that would permit establishing maximum acceptable temperatures for spring, summer, and fall that would protect fish against lethal conditions when subjected to occasional temperature levels exceeding the maximum weekly average temperature during these seasons. These limits, applicable to the receiving water, are summarized in Tables 1 and 2 and are based on the 24-hour median tolerance limit, minus the 2°C safety factor discussed earlier with an acclimation temperature equal to the maximum weekly average temperature. Since these temperatures exceed those permitting satisfactory, albeit sub-optimal growth, unnatural excursions above the maximum weekly average temperature to the maximum temperature should be permitted only in extreme instances and then only for short time periods. The sequence of events relating to gonad development, spawning migration, release of gametes, development of the egg and embryo, and commencement of independent feeding represents one of the most complex phenomena in nature, both for fish (86) and invertebrates (71). These events are generally the most thermally sensitive of all life stages. The erratic sequence of failures and successes of different year classes of lake fish attests to the unreliability of natural conditions for providing optimum reproduction. Uniform elevations of temperature by a few degrees during the spawning period, while maintaining short-term temperature cycles and seasonal thermal patterns, appear to have little overall effect on the reproductive cycle of resident aquatic species, other than to advance the timing for spring spawners or delay it for fall spawners. Such shifts are often seen in nature, although no quantitative measurements of reproductive success have been made in this connection. For example, thriving populations of many fishes occur in diverse streams of the Tennessee Valley in which the date of spawning temperature may vary in a given year by 22 to 65 days. Examination of the literature shows that shifts in spawning dates by nearly one month are common in natural waters throughout the U.S. Populations of some species at the southern limits of their distribution are exceptions - the lake whitefish (Coregonus clupeaformis) in Lake Erie that require a prolonged, cold incubation period (87) and species such as yellow perch (Perca flavescens) that require a long chill period for egg maturation prior to spawning (See 1). Highly mobile species that depend upon temperature synchrony among widely different regions or environments for various phases of the reproductive or rearing cycle (e.g., anadromous salmonids or aquatic insects) could be faced with dangers of dis-synchrony if one area is warmed, but another is not. Poor long-term success of one year class of Fraser River (British Columbia) sockeye salmon (Oncorhynchus nerka) was attributed to early (and highly successful) fry production and emigration during an abnormally warm summer followed by unsuccessful, premature feeding activity in the cold and still unproductive estuary (88). Significant change in temperature or in thermal patterns over a period of time may cause some change in the composition of aquatic communities (i.e., the species represented and the numbers of individuals in each species). Allowing temperature changes to significantly alter the community structure in natural waters may be detrimental, even though species of direct importance to man are not eliminated. Alteration of aquatic communities by the addition of heat may occasionally result in growths of nuisance organisms provided that other environmental conditions essential to such growths (e.g., nutrients) exist. Data on temperature limits or thermal distributions in which nuisance growths will be produced are not presently available due in part to the complex interactions with other growth stimulants. There is not sufficient evidence to say that any temperature increase will necessarily result in increased nuisance organisms. Careful evaluation of local conditions is required for any reasonable prediction of effect.

TABLE 5
Maximum Weekly Average Temperature for Growth and Short-Term Maxima for Survival During the Summer*
(Centigrade and Fahrenheit)

Species	Growth	Maxima
Atlantic Salmon	19 (66)	23 (73)
Bigmouth Buffalo	-	-
Black Crappie	27 (80)	32 (90)
Bluegill	26 (79)	31 (88)
Brook Trout	18 (64)	23 (73)
Carp	-	34 (93)
Channel Catfish	33 (91)	36 (97)
Coho Salmon	18 (64)	24 (75)
Emerald Shiner	28 (82)	31 (87)
Freshwater Drum	-	-
Lake Herring (Cisco)	19 (66)	25 (77)
Largemouth Bass	30 (86)	34 (93)
Northern Pike	28 (82)	30 (86)
Rainbow Trout	19 (66)	24 (75)
Sauger	-	-
Smallmouth Bass	29 (84)	-
Smallmouth Buffalo	-	-
Sockeye Salmon	18 (64)	23 (73)
Striped Bass	-	-
Threadfin Shad	-	-
White Bass	-	-
White Crappie	27 (80)	32 (90)
White Sucker	27 (80)	29 (84)
Yellow Perch	22 (72)	29 (84)

* Based on 24-hour median lethal limit minus 2°C (3.6°F) and acclimation at the maximum weekly average temperature for summer growth for that month.

TABLE 6
Maximum Weekly Average Temperature for Spawning and Short-Term Maxima for Survival During the Spawning Season (Centigrade and Fahrenheit)[≠]

Species	Optimum Spawning	Maximum
Atlantic Salmon	5 (41)	18 (64)
Bigmouth Buffalo	17 (63)	-
Black Crappie	16 (61)	-
Bluegill	25 (77)	31 (88)
Brook Trout	9 (48)	22 (72)
Carp	20 (68)	31 (88)
Channel Catfish	27 (80)	34 (93)
Coho Salmon	10 (50)	22 (72)
Emerald Shiner	23 (73)	29 (84)
Freshwater Drum	21 (70)	-
Lake Herring (Cisco)	4 (39)	18 (64)
Largemouth Bass	21 (70)	30 (86)
Northern Pike	12 (54)	-
Rainbow Trout	9 (48)	-
Sauger	10 (50)	-
Smallmouth Bass	17 (63)	-
Smallmouth Buffalo	17 (63)	-
Sockeye Salmon	10 (50)	22 (72)
Striped Bass	18 (64)	-
Threadfin Shad	18 (64)	-
White Bass	19 (66)	-
White Crappie	18 (64)	-
White Sucker	10 (50)	24 (75)
Yellow Perch	12 (54)	22 (72)

≠ These maxima will also apply during the fall.

* Based on 24-hour median lethal limit minus 2°C (36°F) and acclimation at the maximum weekly average temperature for optimum spawning for that month.

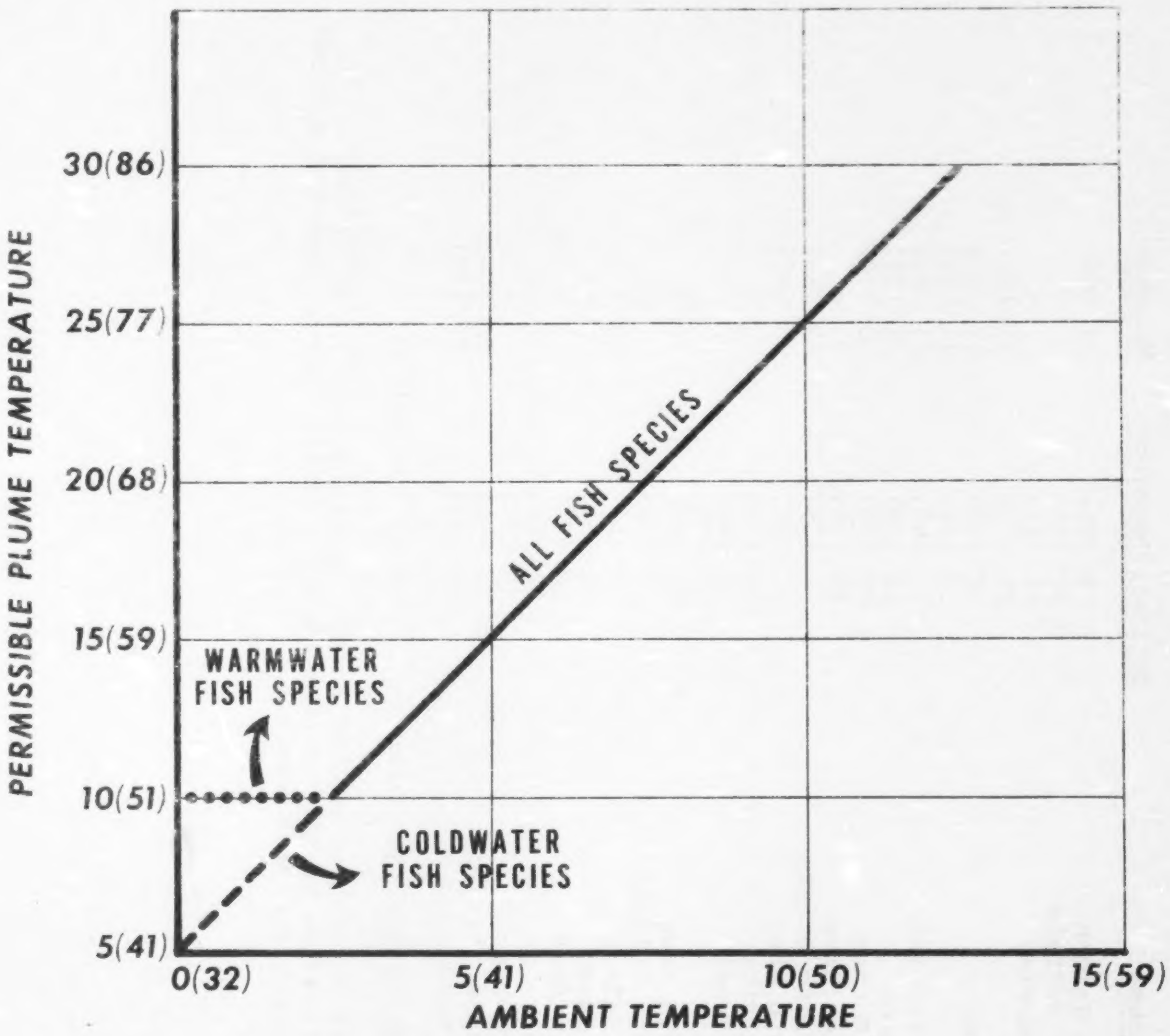

FIGURE 1. NOMOGRAPH TO DETERMINE THE MAXIMUM WEEKLY AVERAGE TEMPERATURE OF PLUMES FOR VARIOUS AMBIENT TEMPERATURES, °C (°F).

EXAMPLE

The nuances of developing freshwater aquatic life criteria for temperature can best be understood by an example (Table 7). Tables 5 and 6 and Figure 1 are the principal sources for the criteria. The following additional information about the specific environment to which the criteria will apply is needed.

1. Species to be protected by the criteria. (In this example, they are bluegill, largemouth bass, and white crappie).

2. Local spawning seasons for these species. (bluegill - May to July; white crappie - April to June; largemouth bass - May to July).

3. Normal seasonal rise in temperature during the spawning season. (Since spawning may occur over a period of a few months and only a single maximum weekly average temperature for optimal spawning is given for a species (Table 6), one would use that optimal temperature for the middle month of the spawning season. In a normal season the criterion for the first month of a three-month spawning

season should be below the maximum weekly average temperature for spawning for the species to be protected, and the last month should be above this temperature. Such a pattern should simulate the natural seasonal rise).

4. Normal ambient winter temperature. (In this case it is 5°C (41°F) in December and January and 10°C (50°F) in November, February, and March. These will be used to determine permissible plume temperatures in the winter (Figure 1).

5. The principal growing season for these species. (In this example, it is July through September. Criteria in Table 5 will be used).

6. Any local extenuating circumstances. (If certain non-fish species or food organisms are especially sensitive and thermal requirement data are avaialable, these data should be used as well as the criteria considered for the fish species).

In some instances there will be insufficient data to determine each necessary criterion for each species (Table 7). One must make estimates based on any available data and by extrapolation from data for species for which there are adequate data. For instance, if the above example had included the white bass for which only the maximum weekly average temperature for spawning is given, one would of necessity have to estimate that its summer growth criterion would approximate that for the white crappie which has a similar spawning requirement.

The choice of desirable fish species is very critical. Since in this example the white crappie is the most temperature sensitive of the three species, the maximum weekly average temperature for summer growth and short-term maxima are based on the white crappie. Consequently, the criteria would result in lower than optimal conditions for the bluegill and largemouth bass. An alternate approach would be to develop criteria for the single most important species even if the most sensitive is not well protected. The choice is a socioeconomic one.

TABLE 7
Criteria Developed for Example[a] (Centigrade and Fahrenheit).

Month	Maximum Weekly Average Temperature Receiving Water	 Heated Plume	Decision Basis
JAN	-[a]	15 (59)	Protection against temperature drop
FEB	-[a]	25 (77)	Protection against temperature drop
MAR	-[a]	25 (77)	Protection against temperature drop
APR	19 (66)	-	White crappie spawning
MAY	21 (70)	-	Largemouth bass spawning
JUN	25 (77)	-	Bluegill spawning and white crappie grow
JUL	27 (80)	-	White crappie growth
AUG	27 (80)	-	White crappie growth
SEP	27 (80)	-	White crappie growth
OCT	21 (70)	-	Normal gradual seasonal decline
NOV	-[a]	25 (77)	Protection against temperature drop
DEC	-[a]	15 (59)	Protection against temperature drop

Month	Short-Term Maximum	Decision Basis
JAN	-	
FEB	-	
MAR	-	
APR	26 (79)	White crappie survival (estimated)
MAY	29 (84)	White crappie survival (estimated)
JUN	32 (90)	White crappie survival
JUL	32 (90)	White crappie survival
AUG	32 (90)	White crappie survival
SEP	32 (90)	White crappie survival
OCT	29 (84)	White crappie survival (estimated)
NOV	-	
DEC	-	

[a] If a species had required a winter chill period for gamete maturation or egg incubation, receiving water criteria would also be required.

B. Wildlife

1. Acidity, Alkalinity and pH

a. pH

The criteria established in the section on aquatic life are considered to be acceptable for wildlife.

Rationale (pH):

Few data are available on the direct effects of pH upon wildlife, but adequate protection would undoubtedly be provided wildlife species and their food organisms if the pH of waters is maintained within the 6.0 - 9.0 range, and provided that a change greater than 0.5 units from the seasonal maximum or minimum does not occur.

b. Alkalinity and Acidity

In wetlands managed primarily as waterfowl habitats, the acceptable bicarbonate alkalinity is between 30 and 130 mg/l, with fluctuations from natural conditions not exceeding 50 mg/l.

Rationale (Alkalinity and Acidity):

The protection extended to aquatic life as established by the criteria in the aquatic life section provides adequate protection for most wildlife species with the possible exception of waterfowl. Productivity of valuable waterfowl pond plants generally increases with increases in bicarbonate alkalinity. Few waters with less than 25 mg/l bicarbonate alkalinity can be classed among the better waterfowl habitats, whereas many waters productive of valuable waterfowl food plants have a bicarbonate alkalinity range of 35 to 200 mg/l (see 1).

2. Light Penetration

Acceptable conditions regarding the combined effects of color and turbidity in water will be met if the compensation point is not changed by more than 10 percent from its seasonally established norm, and if no more than 10 percent of the biomass of photosynthetic organisms is placed below the compensation point by such a change.

Rationale (Light Penetration):

See color, turbidity, suspended and settleable solids in aquatic life section.

3. Solids

a. Salinity

Acceptable conditions regarding salinity in water will be met if salinity levels are maintained as close to natural conditions as possible, and if rapid fluctuations are minimized.

Rationale (Salinity):

All saline water communities from slightly brackish to marine produce valuable waterfowl foods. The most important consideration regarding the effect of salinity upon wildlife is the degree of fluctuations in salinity (1).

b. Settleable substances

Settleable substances should be minimized in order to provide acceptable waterfowl habitats.

Rationale (Settleable substances):

Accumulations of silt are destructive to aquatic plants due primarily to the creation of a soft, semi-liquid substance which is inadequate for the anchoring of rooted plants (1). In Backbay, Virginia, and Currituck Sound, North Carolina, for example, semi-liquid silts up to 13 cm (5 in.) deep cover approximately one-fifth of the total area; this area produces only 1 percent of the total aquatic plant production (1).

4. Specific Harmful Substances

a. Direct Acting

(1). Toxins (Botulism Poisoning)

The factors which affect, or are associated with, botulism poisoning should be managed in such a manner that the risks of outbreaks of the disease are minimized. The factors are insect die-off, water temperature above 21°C (70°F), fluctuating water levels and elevated concentrations of dissolved solids.

Rationale (Botulism Poisoning):

Botulism is a food poisoning caused by the ingestion of the toxin of Clostridium botulinum, a widely distributed anaerobic bacterium. Aquatic birds are highly susceptible to the disease, with the greatest morbidity and mortality rates recorded in shallow alkaline lakes or marshes in the Western United States. Investigation into the causes of botulism have revealed the following possible relationship between environmental factors and high incidence of the disease in shallow alkaline marshes (see 1): 1) Saline waters may support higher invertebrate population levels than relatively fresh waters. (Comparisons, as they relate to avian botulism, have not been made). 2) High salinity may inhibit some of the microorganisms that compete with C. botulinum for nutrients or those that cause deterioration of the toxin. 3) Salinity may have no significant effect on the invertebrates or the bacteria, but it increases the susceptibility of the birds. Cooch (89) has shown that type C botulinum toxin decreases the activity of the salt gland in ducks, reducing its capacity to eliminate salt. Birds so affected succumb to smaller doses of toxin than do those provided with fresh water. Outbreaks of botulism poisoning tend to be associated with or affected by insect die-offs, water temperatures above 21°C (70°F), fluctuations in water levels and elevated concentrations of dissolved solids.

(2). Oils

Visible floating oils on waters inhabited by wildlife are unacceptable.

Rationale (Oils):

Water birds and aquatic mammals require water that is free from surface oils. Heavy mortalities of water birds have resulted from the contaminating of plumages by oil. Exposure of water birds to oil also results in excessive heat loss which accelerates starvation (90), reduces the likelihood of the eggs hatching (91), and may contribute to mortality if the oil is ingested.

b. Acting After Food Chain Magnification

(1). DDT and Derivatives

The maximum acceptable total DDT concentration in aquatic plants and animals is 1 mg/kg on a wet weight basis.

Rational (DDT and derivatives):

DDT and its derivatives DDE and TDE have high lipid solubility and low water solubility and thus tend to concentrate in the living fraction of the aquatic environment (92). DDE is the most stable of the DDT compounds and has been especially implicated in producing thinning of egg shells, increased breakage of eggs, and reproductive failure in species occupying the apex of aquatic food chains in areas with long histories of DDT usage (1). Concentrations of DDE compounds in Lake Michigan have been estimated to be 1 to 3 parts per trillion (93). These levels apparently exceed the concentration which would permit the assured survival of sensitive predatory bird species (1). Available data indicate that total DDT concentrations should not exceed 1 mg/kg in any aquatic plants or animals in order to adequately protect most species of wildlife (1). Present unpublished data indicate effects of even lower levels of DDE to some species of predatory birds (see 1).

(2). Mercury

The maximum acceptable concentrations of mercury in fish is 0.5 ug/g.

Rationale (Mercury):

The 0.5 ug/g limit is consistent with that established for fish in the aquatic life section. Since this level provides little or no margin of safety for fish-eating wildlife, this criterion should be reevaluated as soon as possible.

(3). Polychlorinated biphenyls (PCB's)

The body burdens of PCB's in birds and mammals should not be increased over present levels in order to maintain acceptable levels.

Rationale (Polychlorinated biphenyls):

Although PCB's are widespread environmental containments, their biological effects at present environmental concentrations are not known (1). Because of the persistence of PCB's and their susceptibility to biological magnification, the body burdens of PCB's in birds and mammals should not be permitted to increase and monitoring programs should be instituted.

5. Temperature

Changes in natural freezing patterns and dates should be avoided as far as possible in order to minimize abnormal concentrations of wintering waterfowl.

Rationale (Temperature):

The discharge of warmed industrial and domestic effluents has prompted changes in the normal over-wintering patterns of some waterfowl species in portions of certain northern waters. The attraction of waterfowl to warmed waters near industrial complexes during winter months sometimes creates overcrowding problems. Pollution, food shortage and low air temperature often interact to produce unusually high waterfowl mortalities in their areas (see 1).

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C. Public Water Supply Intake

1. Acidity, Alkalinity, pH

a. Alkalinity

No limit of acceptability is prescribed for the alkalinity of raw water used for drinking water supplies.

Rationale (Alkalinity):

It is not possible to put a specific limit on alkalinity in raw water used for drinking water supplies because the alkalinity of any water is associated with other constituents such as pH and hardness (1).

b. pH

The acceptable pH of raw water used for drinking water supplies is within the range of 5.0 to 9.0.

Rationale (pH):

It is necessary to limit pH to a range of 5.0 to 9.0 in raw water used for drinking water supplies because the treatment process is less expensive and the pH is easier to adjust (1). Waters with a pH below 7.0 are corrosive to water works structures, distribution lines, and household plumbing fixtures and can add such constituents to drinking water as iron, copper, zinc, cadmium and lead (1). High pH values favor corrosion control and values above 8.0 will not dissolve lead (1).

2. Dissolved Gases

a. Ammonia (N)

The acceptable concentration of ammonia (as N) in raw water used for drinking water supplies is 0.5 mg/l.

Rationale (Ammonia):

It is necessary to limit the concentration of ammonia in raw water used for drinking water to 0.5 mg/l because in higher concentrations it has a significant effect on the chlorination process and is indicative of undesirable pollution. The effect of ammonia on the chlorination chlorine is to form chloramine compounds which have considerably less disinfecting efficiency than free chlorine. The cost of chlorine in the treatment process increases when significant concentrations of ammonia are present (1).

b. Dissolved Oxygen

A condition of saturation or near saturation of dissolved oxygen is preferred for drinking water supplies, but no limit of acceptability is prescribed.

Rationale (Dissolved Oxygen):

. There are both advantages and disadvantages to oxygen in public water supplies. Dissolved oxygen in a surface water supply serves as an indicator of the presence of excessive oxygen demanding waste, although there can be exceptions to this rule. Further, when ammonia, iron, or manganese are present in their reduced form, the presence of oxygen precipitates the iron and manganese in the oxidized form, induces the biological oxidation of ammonia to nitrate, and prevents the anaerobic reduction of dissolved sulfate to hydrogen sulfide. For these accomplishments oxygen levels in surface waters should be as near saturation as possible. On the other hand, oxygen does enhance corrosion of treatment facilities and distribution systems, but the benefits of the sustained presence of oxygen in drinking water supplies probably outweigh these disadvantages (1).

3. Inorganics (Ions and Free Elements/Compounds)

a. Arsenic

The maximum acceptable concentration of arsenic in raw water used for drinking water supplies is 0.1 mg/l.

Rationale (Arsenic):

It is necessary to limit arsenic because of its toxicity to humans. Severe poisoning can result from 100 mg, and 130 mg has proved fatal (2). Arsenic can accumulate in the body faster than it is excreted and can build to toxic proportions from small amounts taken periodically through lung and intestinal walls from air, water and food (2). Of 66 major drainage basins and selected water supplies throughout the country, 44 had concentrations of 0.01 mg/l or less, 15 over 0.01 mg/l, and 7 over 0.05 mg/l which indicates the relatively low levels in most of the country's water supply (3). Although the concentration of arsenic in most raw water supplies is naturally below dangerous levels, hazardous concentrations can occur as a result of man's activities. In light of the fact that most of the waters sampled throughout the United States indicated levels of 0.01 mg/l or less, it is reasonable to limit arsenic to not more than 0.1 mg/l in raw water for drinking water supplies.

b. Barium

The maximum acceptable concentration of barium in raw water used for drinking water supplies is 1.0 mg/l.

Rationale (Barium):

Barium should be limited because of its reported serious toxic effects on the heart, blood vessels and nerves of humans. The fatal dose for man is considered to be from 0.8 to 0.9 grams (g) (550 to 600 mg Ba) as the chloride (1). Barium is not known to be cumulative (2). There are no studies available as to how much barium is tolerable in drinking water nor have any studies been made of the long-term effects of the consumption of barium (1). The limit of 1.0 mg/l was derived from the barium in air of 0.5 mg/cubic meter based upon the estimated absorption from the intestines of approximately 2 mg/l (5).

c. Boron

The maximum acceptable concentration of boron in raw water used for drinking water supplies is 1.0 mg/l.

Rationale (Boron):

A sampling of 84 major basins and water supply waters revealed that only 6 waters sampled contained boron in excess of 1 mg/l, only 7 in the range of 0.10 mg/l to 0.50 mg/l, and 28 had less than 0.09 mg/l. It has been reported that 30 mg/l are not harmful to man, which indicates a relatively low toxicity to man and other mammals. Boron is very toxic to many terrestrial plants and could be a problem in watering home gardens, fruit trees, and ornamentals with tap water containing concentrations of boron exceeding 1.0 mg/l (2). Although a much less stringent limit would be sufficient to protect man, such a less stringent limit might encourage degradation of many waters with boron.

d. Cadmium

The maximum acceptable concentration of cadmium in raw water used for drinking water supplies is 0.01 mg/l.

Rationale (Cadmium):

The necessity for limiting the concentration of cadmium in drinking water supplies results from its extremely high toxicity to humans and the fact that conventional treatment, as practiced in the United States, does not remove cadmium (6). There is no evidence that cadmium is biologically essential or beneficial, and it is cumulative in the liver, kidney, pancreas, and thyroid of humans and other animals (2, 1). It has been stated (7) that the absolute amount determines the acute toxicity of cadmium. Symptoms of violent nausea were reported for 29 school children who had consumed fruit sticks containing 13 - 15 mg/l of cadmium (8). This would be equivalent to 1.3 to 3.0 mg of cadmium ingested. A boy was reported to have died within one and one half hours from a dose of about 8.9 grams of cadmium chloride (9). Itai-itai disease syndrome, a severe endemic illness, has been associated with the ingestion of as little as 600 ug/day of cadmium (10). The prescribed level of 10 ug/l is to protect against the intake by humans of more than 20 ug assuming a 2 liter daily consumption of water.

e. Chloride

The maximum acceptable concentration of chloride in raw water used for drinking water supplies is 250 mg/l except in areas where no other drinking water supply source containing less than that concentration is available.

Rationale (Chloride):

This level was based on the fact that chlorides are not removed in conventional treatment and because of taste preference, not toxic to humans (1). The median chloride concentrations detected by taste by a panel of 10 persons were 182, 160, and 372 mg/l from sodium, calcium, and magnesium salts respectively (11).

f. Chromium

The maximum acceptable concentration of total chromium in raw water used for drinking water supplies is 0.05 mg/l.

Rationale (Chromium):

The necessity of restricting concentrations of total chromium to 0.05 mg/l or less results from its adverse physical effects on humans and the fact that there are insufficient data concerning the effectiveness of the defined treatment process in removing chromium in the chromate form. Chromium, in its various valence states, is toxic to man, produces lung tumors when inhaled, and induces skin sensitizations. It occurs in some foods, in air, including cigarette smoke, and in some water supplies (3). No-effect levels for chromate ion on man have not been determined (1). The prescribed limit of 0.05 mg/l was established to avoid jeopardizing the public health by the presence of chromium in drinking water (12).

g. Copper

The maximum acceptable concentration of copper in raw water used for drinking water supplies is 1.0 mg/l.

Rationale (Copper):

Copper should be limited in raw water used for drinking water supplies because it causes taste and corrosion problems and because there is little information on the effectiveness of the defined treatment process in removing copper (1). For 1,577 surface water samples collected at 130 sampling points in the United States 1,173 showed concentrations of 1 to 280 ug/l with a mean concentration of 15 ug/l (13). This indicates the relatively low levels present in the natural waters of the United States, all of which have less than the 1.0 mg/l specified criterion. Since copper is an essential and beneficial element in human metabolism and because a normal diet barely provides an adequate amount, it is desirable to have small amounts in drinking water. Although small amounts of copper are beneficial to humans, large doses may produce emesis, or if prolonged, result in liver damage. The prescribed limit is based on considerations of taste rather than hazard to health (1).

h. Iron

The maximum acceptable concentration of soluble iron in raw water used for drinking water is 0.3 mg/l.

Rationale (Iron):

Soluble iron in excess of the prescribed limit begins to be detectable by imparting undesirable tastes to drinking water, to result in rust deposits in distribution systems and to stain clothes during laundering (1). The iron intake from food provides 7 to 35 mg per day, with an average of 16 mg (3).

i. Lead

The maximum acceptable concentration of lead in raw water used for drinking water supplies is 0.05 mg/l.

Rationale (Lead):

Lead is toxic to humans and there is little information concerning the effectiveness of its removal by conventional treatment (1). For the 100 largest cities in this country, finished waters were found (14) to have a maximum lead concentration of 0.062 mg/l and a median of 0.0037 mg/l. It has also been found (15) that finished water in 969 water supplies have lead concentrations ranging from 0 to 0.64 mg/l with concentrations in fourteen of the supplies sampled exceeding the prescribed limit of 0.05 mg/l. Another study (6) of 74 of the major basins found few to contain lead concentrations in excess of the prescribed limit, but the excessive concentrations generally resulted from man caused sources. Acute toxicity is most common in children and is manifested by anorexia, vomiting and convulsing due to intracranial pressure. Chronic toxicity symptoms are anemia, weakness and weight loss in children and vague gastorintestinal and central nervous system complaints by adults (16). Daily intake of 0.5 to 0.6 mg of lead by adults under controlled conditions resulted in a small retention but no detectable deviation from normal health of the individuals. Indirect evidence from tests on industrial workers exposed to known amounts of lead supported these findings (17). The exception to the above was prevalent in children where lead intoxication was recorded based upon both tolerated intake and severity of symptoms (18). It is reported (1) that with a lead intake of 0.6 mg per day, development of lead intoxication by humans is unlikely. The prescribed limits are established to provide protection based upon the foregoing and the combined likely exposure from both food and water.

j. Manganese

The maximum acceptable concentration of soluble manganese in raw water used for drinking water supplies is 0.05 mg/l.

Rationale (Manganese):

The concentration of manganese must be limited in raw water sources for drinking water to prevent aesthetic and economic damage, to avoid possible physiologic effects due to excessive intake by humans, and because soluble manganese is not removed by conventional treatment (3). Manganese has been reported to affect the taste of drinking water at levels as low as 0.05 mg/l (2), and to stain laundry at levels as low as 0.1 mg/l (19).

k. Mercury

The maximum acceptable concentration of total mercury in raw water used for drinking water supplies is 0.002 mg/l.

Rationale (Mercury):

The necessity of limiting mercury in raw water used for drinking water supplies results from its extreme toxicity to humans and other animals and because conventional treatment does not remove it. All of the organic forms of mercury (alkoxy, alkyl, and aryl) are toxic, but the alkyl form is the most toxic tc man. The accumulation and retention of these mercurials in the nervous system, the ease of their transmittal across the placenta, and their effect on developing tissue make them particularly dangerous to man (12). Based upon available epidemiological evidence, the lowest whole blood concentration of methyl mercury associated with toxic symptoms is 0.2 ug/g, which corresponds to prolonged, continuous intake by man of approximately 0.3 mg Hg/70 kg/day. To provide a safety factor of 10, the maximum dietary intake should be 0.03 mg Hg/person/day (30 ug/70 kg/day). This assumes the consumption of 420 g/wk of fish containing 0.5 mg Hg/kg and 2 liters of water daily containg 0.002 mg/l mercury. If all of the mercury is not in the alkyl form, or if fish consumption is limited, a greater factor of safety will exist.

1. Nitrate-Nitrite

1. Nitrate

The maximum acceptable concentration of nitrate-nitrogen in raw water used for drinking water supplies is 10 mg/l.

2. Nitrite

The maximum acceptable concentration of nitrite-nitrogen in raw water used for drinking water supplies is 1.0 mg/l.

Rationale (Nitrate-Nitrite):

Nitrates in drinking water at higher levels than the prescribed limit have had adverse physiological effects on infants and treatment does not remove them. A survey of reported cases of nitrate poisoning found that there were no cases of poisoning where drinking water concentrations of nitrate-nitrogen were less than 10 mg/l. Concentrations of nitrate-nitrogen ranging from 15-250 mg/l have been reported to cause infantile nitrate poisoning which is called methemoglobinemia (3). Methemoglobinemia is largely confined to infants less than three months old and results from bacterial conversion of nitrate ion to nitrite which in turn converts hemoglobin to methemoglobin (1). Nitrite poses a greater hazard in drinking water than nitrate, but it seldom occurs in dangerous concentrations (12) except where it is introduced as an anticorrosion agent (3). Drinking water supplies having concentrations of nitrite-nitrogen over 1.0 mg/l should not be used for infant feeding (12).

m. Phosphate

No limit of acceptability is prescribed for phosphate in raw water used for drinking water supplies.

Rationale (Phosphate):

Although two primary benefits of phosphate (P) limits would be the avoidance of problems associated with algae and other aquatic plants as well as coagulation problems due particularly to complex phosphates, the total complexity of the problem does not permit the establishment of an acceptable limit for phosphates in drinking water supplies. Critical phosphorus concentrations vary with other water quality characteristics. Turbidity and other factors at times negate the algae-producing effects of high phosphorus concentrations, and phosphorus concentrations in lakes and reservoirs are often reduced to some extent by precipitation (1). Although most relativly uncontaminated lake districts are known to have surface waters that contain less than 30 ug/l total phosphorus (20), earlier surveillance data from stations sampled across the country indicated (21) 48 percent had phosphorus concentrations in excess of 50 ug/l. Some potable surface water supplies are reported to exceed 200 ug/l (P) without noticeable problems due to aquatic growths (1).

n. Selenium

The maximum acceptable concentration of selenium in raw water used for drinking water supplies is 0.01 mg/l.

Rationale (Selenium):

This limit is considered necessary because conventional treatment does not remove selenium and because so little is known of its potential toxicity to humans when ingested in water. It has been reported that the intake of selenium in food in seleniferous areas may range from 600 to 6,340 ug/day, which is close to the estimated levels at which symptoms of (chronic) selenium toxicity occur in man (23). If data on selenium in foods (23) are applied to the average consumption of foods (24), the normal intake of selenium is about 200 ug/day. The toxicity of selenium resembles that of arsenic and can, if exposure is sufficient, cause death (1).

o. Silver

The maximum acceptable concentration of silver in raw water used for drinking water supplies is 0.05 mg/l.

Rationale (Silver):

Conventional public water supply treatment systems are not designed to remove silver. The principal effect of silver in the body is cosmetic. It causes a condition known as argyria whereby a gray discoloration of skin, eyes and mucous membranes occurs (1). It is calculated that the prescribed amount could be ingested for a lifetime without causing argyria (3). Argyria is a condition resulting from the deposition of silver in the skin of humans which causes a permanent gray discoloration and any amount over 1 gram of silver in the human body will result in this condition (24, 25). It is not known to harm individuals affected in any way other than that it is very unsightly (3). For these reasons and because there is very little information on the toxicity of silver to humans, it is considered necessary to limit silver in raw water used for drinking water supplies.

p. Sodium

No limit of acceptability is prescribed for sodium in raw water used for drinking water supplies.

Rationale (Sodium):

Because a healthy individual can consume sodium to fit his food selection and seasoning without ill effect, no limit was placed on the acceptable concentration of sodium in raw water used for drinking water supplies(1). It is reported (26) that the intake of sodium may average 6 gr/day without ill effects on health. However, portions of the population suffering from hypertension and edema associated with cardiac failure are instructed by their physicians to limit their sodium intake (1). The cost of removing sodium from raw water is excessive and the limited concentrations found in most raw water are generally lower than the limits recommended for those on a moderately restricted sodium diet.

q. Sulfate

The maximum acceptable concentration of sulfate in raw water used for drinking water supplies is 250 mg/l except in areas where no other drinking water supply source containing less than that concentration is available.

Rationale (Sulfate):

Sulfates should be limited because conventional treatment does not remove them, and because, at levels greater than 250 mg/l, they cause taste problems. A threshold laxative effect was reported at concentrations of 600 mg/l and at lower concentrations in waters having magnesium concentrations above 200 mg/l in addition to the sulfate (see 1).

r. Zinc

The maximum acceptable concentration of zinc in raw water used for drinking water supplies is 5.0 mg/l.

Rationale (Zinc):

Concentrations of zinc must not exceed 5 mg/l in raw water used for drinking water supplies because higher levels cause an undesirable taste which survives through conventional treatment and remains in substantial amounts in finished drinking water. Zinc is not a health problem, but is essential in human metabolism as well as being a required constituent of a number of body enzymes. Humans take in from all sources a daily average of from 10 to 15 mg of zinc (1). One taste threshold test reported that 5 percent of the observers were able to detect the presence of 4.3 mg/l as zinc sulfate in distilled water (27).

4. Microbiological Indicators

a. Bacteria

The maximum acceptable coliform concentration in raw water used for drinking water supplies is 10,000/100 ml for total coliforms and 2,000/100 ml for fecal coliforms.

Rationale (Microbiological Indicators):

Presence of coliforms, and more significantly fecal coliforms, in water is indicative of fecal pollution. In general, the presence of fecal coliform organisms indicates more recent and possibly dangerous fecal contamination. When the count of fecal coliforms exceeds 2,000 there is a high correlation with increased numbers of both human pathogenic viruses and human pathogenic bacteria (28, 29, 30). A conventional water treatment plant is capable of removing most pathogenic bacteria at the level of 2,000 fecal coliforms per 100 ml; however, when this number of fecal coliforms is exceeded the probability of transmitting pathogenic organisms in finished drinking water increases.

b. Viruses

No limit of acceptability is prescribed for viruses in raw drinking waters.

Rationale (Viruses):

There is presently a lack of data indicating which viral group provides a consistent indication of potential fecal contamination and threat to human health. Also, risk factors are not yet available. Virological techniques have as yet not been perfected so as to allow monitoring of water. For these reasons no criterion or criteria are given for viruses in raw drinking waters.

5. Organic Compounds

a. Carbon Adsorbable

The maximum acceptable concentration of organics - carbon adsorbable is 0.3 mg/l CCE and 1.5 CAE, both measured by the "low-flow carbon adsorption method (CAM)" technique, in raw water used for drinking water supplies.

Rationale (Carbon Adsorbable):

Limiting the concentration of organics-carbon adsorbable in raw water used for drinking water supplies is necessary because they are aesthetically undesirable, may have adverse physiological effects, and are not removed by conventional treatment. Organics - carbon adsorbable, as used here, contains two parts, carbon-chloroform extract (CCE) and carbon alcohol extract (CAE) both of which have an operational definition (32). The presence of insecticides, acrylonitrile phenylether, polycyclic hydrocarbons, kerosene, and substitute- benzene compounds have been demonstrated in CCE materials, while ABS and organic fatty acids have been identified in CAE materials.

The toxicity of CAM sampler extracts from raw and finished surface water was tested in 1963 (33). They found that the mixture of organics in the CCE from both the raw and finished water was carcinogenic to rats upon subcutaneous injection. Similar testing with CAE's did not produce tumors, but their rat life-time data was reanalyzed to demonstrate life-shortening caused by subcutaneous injection of CAE from both raw and finished water. Water having concentrations exceeding the prescribed limits may contain undesirable and unwarranted materials and represent a generally unacceptable level for unidentified organic substances (1).

b. Cyanides

The maximum acceptable concentration of cyanides in raw water used for drinking water supplies is 0.2 mg/l.

Rationale (Cyanides):

It is necessary to limit cyanides in raw water for drinking water supplies mainly because of its toxicity to man. The human body has an innate capacity to convert cyanide to the less toxic cyanate. Toxicity effects occur when the intake of cyanides overwhelms this detoxifying mechanism. The safe threshold toxicity limit for human ingestion of water at 2 liters per day is concentrations of 19 mg/l. A single dose of from 50 to 60 mg is reported to be fatal to man (16).

c. Foaming Agents

The maximum acceptable concentrations of foaming agents determined as methylene blue active substances is 0.5 mg/l in raw water used for drinking water supplies.

Rationale (Foaming Agents):

The most common foaming agents are synthetic anionic surfactants, the most important being linear alkylate sulfonate (LAS). Foaming agents can produce unsightly masses of foam in a stream or in tap waters. Conventional waste treatment reduces concentrations in waters; however, measurable levels are present in the nation's surface and ground waters. Although methyl blue active substances (MBAS) is a more specific measure of anionic surfactants and does not respond to cationic or nonionic surfactants, the MBAS values are the best available measure of surfactants in water.

d. Nitrilotriacetate (NTA)

No limit of acceptability is prescribed for NTA at this time.

Rationale (NTA):

It is not possible to establish limits for NTA at this time because the necessary information and data to do so are unavailable. The affinity of NTA for toxic metals is not known and its toxicity to man is also unknown.

e. Oil and Grease

Oil and grease should be essentially absent from raw water used for drinking water supplies.

Rationale (Oil and Grease):

Oil and grease, as defined in Standard Methods (38), in public water supplies in any amount will cause taste, odor, and appearance problems (34, 35, 36, 37, 38) and may be hazardous to man (39, 2) and are detrimental to conventional treatment processes. It is virtually impossible to express the limits in numerical units (4). The smallest amounts of these substances can be the cause of raw water rejection for drinking water supplies because conventional treatment does not remove them all (1).

f. Phenols

The maximum acceptable concentration of phenolic compounds in raw water used for drinking water supplies is 1.0 ug/l.

Rationale (Phenols):

It is necessary to limit phenolic compounds in raw water used for drinking water supplies because they are not generally removed by conventional treatment. They cause odor problems at low concentrations, and the chlorination process may form chlorophenols which are odor detectable at lower concentrations than other phenols. It is reported (1) that trace concentrations of phenolic compounds less than 1.0 mg/l affect the organoleptic properties of drinking water. The p-cresol threshold odor concentration has been determined to be 0.055 mg/l, the m-cresol 0.25 mg/l and cresol 0.26 mg/l. Phenol has been shown to have a threshold odor concentration of 4.2 mg/l (40) whereas the values for the chlorinated phenols are 2-chlorophenol, 2.0 ug/l and 4-chlorophenol, 250 ug/l (41).

g. Phthalate Esters

No limit of acceptability is prescribed for phthalate esters in raw water for drinking water supplies at this time.

Rationale (Phthalate Esters):

Phthalates in water represent a potential but unknown health problem and have been implicated in growth retardation, accumulation and toxicity. Insufficient information on their effects on man is available (1).

h. Polychlorinated Biphenyls (PCB's)

No limit of acceptability is prescribed for acceptable concentrations of polychlorinated biphenyls in raw water used for drinking water supplies.

Rationale (PCB's):

Too little is known about the levels in water, the retention and the accumulation in humans and the effects of very low rates of ingestion to permit the establishment of acceptable PCB limits.

6. Pesticides

Pesticides are comprised of numerous organic compounds that are used for specific and general purposes. Included are the chlorinated hydrocarbons and organophosphorus compounds, as well as the chlorophenoxy and other herbicides. They have been reported as generally useful in improving agricultural yields, reducing the mass growth of nuisance causing aquatic plants, and controlling disease vectors. Pesticides differ widely in chemical and toxicological characteristics, and their biochemistry is only partially known. Their toxicity to man and biodegradability vary considerably between compounds, and because of this they will be considered separately as follows (1):

a. Insecticides - Chlorinated Hydrocarbons

The maximum acceptable concentrations of chlorinated hydrocarbon insecticides in raw water used for drinking water supplies are listed in Table 8.

Rationale (Insecticides - Chlorinated Hydrocarbons):

The chlorinated hydrocarbons are one of the most important groups of synthetic organic insecticides because of their sizeable number, wide use, stability in the environment, toxicity to some wildlife and non-target organisms, and their adverse physiological effects on humans. Also, there is insufficient information on the effects of treatment in removing these compounds (1). The chlorinated hydrocarbons are stored in fatty tissues rather than being rapidly metabolized. Regardless of how chlorinated hydrocarbons enter organisms, they induce poisoning having similar symptoms but which differ in severity. The severity is related to the extent and concentration of the compound in the nervous system, primarily the brain (42). Mild cases cause headaches, dizziness, gastrointestinal disturbances, numbness and weakness of the extremities, apprehension and hyperirritability. In severe cases, there are muscular fasciculations spreading from the head to the extremities followed eventually by muscular spasms, leading in some cases to convulsions and death. The maximum allowable concentrations for chlorinated hydrocarbons in raw water used for drinking water supplies in Table 8 were calculated from levels considered safe to man and other animals and from the known total intake by man of these substances from all sources (1).

b. Insecticides - Organophosphate and Carbamate

The maximum acceptable concentration of organophosphorus insecticides is 0.1 mg/l in raw water used for drinking water supplies.

Rationale (Insecticides - Organophosphorus and Carbamate):

It is necessary to place a limit on the concentrations of these substances in raw water used for drinking water supplies because of their high mammalian toxicity and because their fate, during conventional treatment, is unknown. The use of these pesticides in the agriculture industry to control insects has shown a steady increase. The majority of these pesticides are somewhat similar in chemical structure as well as in physical and biological properties (1). Although different from each other to some extent they all act by the same physiological mechanism (1). Ingestion of these pesticides results in a dysfunction of the cholinesterase of the nervous system when ingested in small quantities over a long period of time (43). Studies using organophosphorus compounds on human volunteers provided indications of harmful levels. One study estimated that 100 mg of parathion would be lethal and that 25 mg would be moderately toxic (44). On the basis of various studies it was concluded that 5 mg/day (0.07 mg/kg/day) of parathion, the most toxic substance in this group, should be a safe level for man (1). After application of a factor of safety of 25 for parathion a safe limit of 0.1 mg/l was derived.

TABLE 8

Recommended Limits for Chlorinated Hydrocarbon Insecticides

		Long-Term Levels With Minimal or No Effects		Calculated Maximum Safe Levels From All Sources of Exposure			Intake From Diet		Water	
Compound	Species	ppm in diet	mg/kg/body weight/day[a]	Safety Factor (X)	mg/kg/day	mg/man/day[b]	mg/man/day	% of Safe Level	% of Safe Level	Recommended[c] limit (mg/l)
Aldrin	Rat	0.5	0.083	1/100	0.00083	0.0581	0.0007	5.0	20	0.001
	Dog	1.0	0.02	1/100	0.0002	0.014[d]				
	Man	-	0.003	1/10	0.0003	0.021				
Chlordane	Rat	2.5	0.42	1/500	0.00084	0.0588[d]	T	T	5	0.003[e]
	Dog	N.A.	N.A.	-	-	-				
	Man	N.A.	N.A.	-	-	-				
DDT	Rat	5.0	0.83	1/100	0.008	0.56[d]	0.021	3.4	20	0.05
	Dog	400.0	8.0	1/100	0.08	5.6				
	Man	-	0.5	1/10	0.05	3.5				
Dieldrin	Rat	0.5	0.083	1/100	0.00083	0.0581	0.0049	35.0	20	0.001
	Dog	1.0	0.02	1/100	0.0002	0.014[d]				
	Man	-	0.003	1/10	0.0003	0.021				
Endrin	Rat	5.0	0.83	1/500	0.00166	0.1162	0.00035	4.1	20	0.0005
	Dog	3.0	0.06	1/500	0.00012	0.0084[d]				
	Man	N.A.	N.A.	-	-	-				
Heptachlor	Rat	0.5	0.083	1/500	0.000166	0.01162	0.00007	0.6	2	0.0001[f]
	Dog	4.0	0.08	1/500	0.00016	0.0112[d]				
	Man	N.A.	N.A.	-	-	-				
Heptachlor Epoxide	Rat	0.5	0.083	1/500	0.000166	0.01162	0.0021	150.0	5	0.0001
	Dog	0.5	0.01	1/500	0.00002	0.0014[d]				
	Man	N.A.	N.A.	-	-	-				
Lindane	Rat	50.0	8.3	1/500	0.0166	1.162	0.0035	8.3	20	0.005
	Dog	15.0	0.3	1/500	0.0006	0.042[d]				
	Man	N.A.	N.A.	-	-	-				
Methoxychlor	Rat	100.0	17.0	1/100	0.17	11.9[d]	T	T	20	1.0[e]
	Dog	4000.0	80.0	1/100	0.8	56.0				
	Man	-	2.0	1/10	0.2	14.0				
Toxaphene	Rat	10.0	1.7	1/500	0.0034	0.238[d]	T	T	2	0.005[e]
	Dog	400.0	8.0	1/500	0.016	1.12				
	Man	N.A.	N.A.	-	-	-				

Legend: a/ Assume weight of rat - 0.3 kg and of dog - 10 kg; assume average daily food consumption of rat - 0.05 kg and of dog - 0.2 kg.

b/ Assume average weight of human adult - 70 kg.

c/ Assume average daily intake of water for man - 2 liters.

d/ Chosen as basis on which to derive recommended limit.

e/ Adjusted for organoleptic effects.

f/ Adjusted for interconversion to H. epoxide.

N.A. No data available

T Infrequent occurrence in trace quantities

Source (1)

c. Herbicides - Chlorophenoxy

The maximum acceptable concentrations of 2,4-D, 2,4,5-T, and Silvex in raw water used for drinking water supplies are 0.02, 0.002, and 0.03 respectively.

Rationale (Pesticides - Chlorophenoxy):

It is necessary to limit the concentrations of these substances in raw water used for drinking water supplies because of their possible adverse physiological effects on man and insufficient information on the effectiveness of the conventional treatment in removing these substances. Studies of the acute oral toxicity of chlorphenoxy herbicides upon various animal species indicate as much as a threefold variation and toxicities (all compounds) of about the same magnitude within each species (45, 46). The LD_{50} of one species, the rat, was 500 mg/kg during a 21-day period (58). One case of 2,4-D poisoning in man has recently been reported (47). A study of 2,4-D on rats and dogs indicated no-effect levels of 0.5 mg/kg/day and 8.0 mg/kg/day respectively (48). A 2-year study found the no-effect levels of Silvex to be 2.6 mg/kg/day in rats and 0.9 mg/kg/day in dogs (49). Experiments on mice and rats give evidence of teratogenic effects and embryo toxicity effects from 2,4,5-T with the rat being more sensitive. A dosage of 21.5 mg/kg produced no harmful effects in mice but 4.6 mg/kg caused minimal but statistically significant effects in rats (50).

7. Physical

a. Color

Maximum acceptable limits for color in raw water used for drinking water supplies are 75 platinum-cobalt units.

Rationale (Color):

Colored substances can chelate metal ions thereby interfering with coagulation (51), and can reduce the capacity of ion exchange resins (52). The prescribed limit for color in raw water used for drinking water supplies is necessary to permit the production of water meeting drinking water standards by using only moderate dosages of coagulant chemicals. Also at optimum pH the required coagulant dosage is reported to be linearly related to the color of the raw water (4). Color in finished water supplies is aesthetically undesirable to the consumer and economically undesirable to some industries, but can be removed by treatment processes (53, 54).

b. Odor

To be acceptable for drinking water supplies, raw water should be essentially free of any substance causing odor problems.

Rationale (Odor):

The primary means of determining the acceptability of drinking water are odor and taste. Above a certain threshold level drinking water becomes objectionable and will most likely be rejected by the users who will then turn to other sources that may be less safe (1). The effectiveness of conventional treatment in removing odor causing substances is highly variable, depending on the nature of the material causing the odor, and cannot be depended upon. This is the reason that it was not feasible to prescribe odor limits in terms of a threshold odor number

(4). It is indicated (3) that an odor in polished drinking water becomes objectionable above a threshold number of three.

c. Temperature

Temperature changes that detract from the potability of public water supplies or that otherwise interfere with the treatment process are unacceptable.

Rationale (Temperature):

Although no limit of acceptable temperature is prescribed, temperature changes in raw water used for drinking water supplies should be held to a minimum. Changes in temperature can adversely affect the quality of raw water and interfere with conventional treatment processes used to produce drinking water. Temperatures above certain levels intensify taste and odor through increased volatility of the source compound and thus affect the water's palatability (55). The growth of taste and odor producing organisms may be stimulated by artificially increasing temperatures (56, 57, 58). Increase of temperature or temperature changes during the standard treatment process can adversely affect coagulation, sedimentation, filtration, and chlorination (59, 60, 61, 62) though it would be desirable, the establishment of numerical limits on temperature and temperature change is not feasible.

d. Turbidity

No limits of acceptability are prescribed for turbidity in raw water to be used for drinking water supplies.

Rationale (Turbidity):

No limits are placed on turbidity of raw water used for water supplies because the customary methods for measuring and reporting turbidity are inadequate for quantifying those characteristics harmful to public water supplies and water treatment processing. For instance, water may coagulate more rapidly with 30 Jackson turbidity units than water with 5 or 10 units, or water with 30 Jackson turbidity units may sometimes be more difficult to coagulate than water with 100 units. It can be seen, therefore, that a valid turbidity criteria in Jackson turbidity units cannot be established. It is also not possible, in light of present knowledge, to establish limits in mg/l of nonfilterable and undissolved solids because the type of plankton, clay, or earth particles, their size and electrical charge are more determining factors. It is stated that the amount of turbidity in water must relate to the ability of a treatment plant to economically remove it. Most treatment plants are designed to remove the turbidity existing at the time the plant is constructed. Any increase of turbidity over that for which the plant is designed should not be allowed (4).

8. Radioactivity

Standards for radioactivity in drinking water usually apply to finished drinking water. Depending on the physical and chemical properties of the radioactive material, such commonly used water treatment processes as filtration, settling, softening, etc , may reduce the radioactivity present in the raw water used for input to drinking water supplies, so that the radiological quality of the raw drinking water is not necessarily indicative of the quality of the finished waters.

When raw water is consumed directly, the maximum acceptable concentration of naturally occurring radionuclides having alpha ray emitting daughters, e.g., radium-226, -228, etc. is 5 pCi/1; and the maximum acceptable aggregate dose to the population served by the water supply is 3000 man-rem/year, unless the radium-226 activity is less than 0.5 pCi/1.

Concentrations of man-made radionuclides that result in an average dose rate to the whole body or any specific organ exceeding 25 man-rem per year and/or and aggregate dose to the population served by the water supply exceeding 3000 man-rem/year are unacceptable. This aggregate dose limit shall not apply to strontium-90 exposures from atomic bomb fallout.

Rationale (Radioactivity):

Criteria for drinking water cannot be based on an assumed harmless level of radiation dose. Rather, controls for both individual and population exposures should be based on the prudent assumption that there is no threshold dose for ionizing radiation and that any health effects would be proportional to the dose delivered by the ingested activity (67). Since the absence of health effects cannot be assumed, the radiological quality of water must meet two criteria. Not only must the risk to a prudent individual using the water supply be so small as not be a cause of undue concern but the health impact on the total population using the water supply also must be limited, a criterion best met by considering the sum total of all the individual doses received by those persons using the supply. This aggregate dose, in units of man-rem, should be so small that regardless of the number of persons using the supply there is a reasonable expectation of minimal health effects in any given year. It is recognized that a limit on aggregate dose allows the dose to individuals to vary within the limit set for individual risk depending on the size of the water supply systems. However, it also requires dose reduction to be instituted as the population served by a supply increases.

An acceptable risk to individuals is usually not considered in the development of criteria for drinking water, since it is expected that all health effects can be averted. Because this cannot be reasonably assumed in the case of radioactive contamination, selection of an acceptable risk depends on societal values. The conservative assumption made here is that water supply users will not accept any level of radioactivity that would cause a meaningful increase in the probability that an individual will develop cancer. Estimates of the increased cancer risk from small doses of ionizing radiation are available, but it must be recognized that such estimates, though reflecting a mature analysis of the best available data, are still subject to a certain degree of uncertainty. Nevertheless, a study of the information given in reference 1 indicates a 25 mrem per year limit on the risk from drinking water, is small enough to insure that any attendant cancer risk is not likely to involve more than one in a hundred thousand persons per year of exposure.

In case of radium contamination, dose reductions may be realized by water treatment, such as softening, dilution with less radioactive water (usually surface waters) or by switching entirely to a raw water supply containing a lower concentration of radioactivity. In all cases such alternatives should consider both the effect of such changes on the overall quality of the finished drinking water and the most economical means of realizing the required dose reduction. Because the daily intake of radium-226 from food usually equals or exceeds 1 pCi, the amount of radium in the skeleton is relatively insensitive to the quantity of radium-226 in drinking water at concentrations less than 0.5 pCi/l. Considering the high costs of removing radium at such low concentrations, it is usually more effective to control other routes of radionuclide ingestion.

9. Solids

a. Dissolved Solids

No limits of acceptability are prescribed for total dissolved solids in raw water for drinking water supplies.

Rationale (Dissolved Solids):

It is not considered necessary to prescribe limits on total dissolved solids in raw water used for drinking water supplies because the two most troublesome salts in total dissolved solids are limited elsewhere in the criteria. These salts are chloride and sulfate.

b. Hardness

No limit of acceptability for hardness in raw water used for drinking water supplies is prescribed.

Rationale (Hardness):

It is not possible to place a specific limit on hardness in raw water used for drinking water supplies (1, 4). It is reported (77, 78, 79) that the metal ions which affect the hardness of water are of no concern to human health, although there are indications that they may influence the effect of other metal ions on some organisms. Hardness in water is largely a function of the composition of geological formations of the area in which the water is located. The acceptability of a given water supply is determined by consumer preference and is often related to the hardness to which the public has become accustomed (1).

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VI Marine Water Constituents (Aquatic Life)

A. Aquatic Life

1. Acidity, Alkalinity, pH (Buffer Capacity)

The acceptable range of pH is 6.5 to 8.5. Within this range fluctuation of 0.2 units in either direction from normal are acceptable.

Rationale (pH):

Despite the great emphasis on the importance of pH in the existing literature, very little is known of its direct physiological effects on marine organisms. It is known, however, that pH changes in the marine environment can be extremely significant. Even a slight change in pH indicates that the buffering capacity of sea water has been drastically altered and that a potential or actual carbon dioxide imbalance exists. In addition, when the pH of receiving sea water changes, the duration of the variation can be extremely important to the survival of organisms. The normal pH range in sea water is considerably narrower than that found in fresh waters. At the surface of the sea, pH normally varies from 8.0 to 8.3, depending on the partial pressure of carbon dioxide in the atmosphere and the salinity and temperature of the water. In shallow, biologically-active waters, however, particularly in warm tropical areas, there is a large diurnal variation in pH, with values as high as 9.5 in the daytime and as low as 7.3 at night or in the early morning. Plankton and benthic invertebrates are probably more sensitive than fish to changes in pH. Oysters appear to survive best in brackish waters when the pH is about 7.0. At a pH of 6.5 and lower, however, the rate of pumping decreases notably and the time the shells remain open is reduced by 90 percent (1, 2). Oyster larvae are damaged at a pH of 9.0 and killed at 9.1 in a few hours, and the upper pH limit for crabs has been reported as 10.2 (3).

2. Dissolved Gases

a. Ammonia

The maximum acceptable concentration of ammonia in marine or estuarine waters is 1/10 (0.1) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of un-ionized ammonia in marine or estuarine waters in excess of 0.4 mg/l are unacceptable.

Rationale (Ammonia):

Most of the information available on the toxicity of ammonia is for freshwater organisms. However, because of the slightly higher alkalinity of sea water and the larger proportion of un-ionized ammonium hydroxide, ammonia may be more toxic in sea water than in fresh water (4).

b. Chlorine

The maximum acceptable concentration of free residual chlorine in marine and estuarine waters is 1/10 (0.1) of the 96-hour LC$_{50}$ value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of free residual chlorine in marine or estuarine waters in excess of 0.01 mg/l are unacceptable.

Rationale (Chlorine):

Chlorine is generally present in the stable chloride form which constitutes about 1.9 percent of sea water. Elemental chlorine, which is a poisonous gas at normal temperature and pressure, is generally produced by electrolysis of a brine solution. When dissolved in water, chlorine gas completely hydrolizes to form hypochlorous acid (HOCl) or its dissociated ions; at concentrations below 1000 mg/l no chlorine exists in solution as Cl . The dissociation of HOCl to H+ and OCl- depends on the pH: 4 percent is dissociated at pH 6, 25 percent at pH 7, and 97 percent at pH 9; the undissociated form is the most toxic (5). Although free chlorine is toxic in itself to aquatic organisms, combinations of chlorine with ammonia, cyanide, and organic compounds such as phenols and amines, may be even more toxic and can impart undesirable flavors to seafood. Chlorine is one of the few elements for which experimentation has demonstrated the specific toxicity of the chemical to marine organisms. Studies of irritant responses of marine fishes to chlorine showed a slight irritant activity at 1 mg/l and violent irritant activity at 10 mg/l (6). Oysters are sensitive to chlorine concentrations of 0.01 to 0.05 mg/l and react by reducing pumping activity. At higher Cl^- concentrations of 1.0 mg/l, effective pumping could not be maintained (7). Adult mussels (*Mytilus edulis*) were killed by exposure to 2.5 mg/l of chlorine within 5 days (8). Two species of copepods (*Acartia tonsa* and *Eurytemona affinis*) showed extremely rapid mortality to low doses of chlorine (9). The LD_{50} for *Acartia* at 10 mg/l of chlorine was 36 seconds; the LD_{50} for *Eurytemona* at a similar dose was 120 seconds.

c. Hydrogen Sulfide

The maximum acceptable hydrogen sulfide concentration in marine or estuarine waters is 0.1 of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of hydrogen sulfide in excess 0.01 mg/l in marine or estuarine waters are unacceptable.

Rationale (Hydrogen Sulfide):

Sulfides are quite toxic to marine organisms, due in part to their fairly high solubility in water. At 20 degrees C. hydrogen sulfide is soluble in water to the extent of 4,000 mg/l (3). Further, the toxicity of sulfides to fish increases as the pH decreases (10). Small amounts of hydrogen sulfide are fatal to sensitive species such as trout at concentrations of 0.05 mg/l, even in neutral and somewhat alkaline solutions (11). Bioassays with Pacific salmon (*Oncorhynchus kisutch*) and sea trout (*Salmo clarkii*) demonstrated toxic effects from hydrogen sulfide at 1.0 mg/l (12, 13, 14). Hydrogen sulfide in bottom sediments can affect benthic invertebrate populations (15).

d. Dissolved Oxygen

Minimum acceptable dissolved oxygen levels in marine or estuarine waters are 6.0 mg/l, except when temporary natural phenomena cause this value to be decreased. Dissolved oxygen concentrations below 4.0 mg/l in marine or estuarine waters are unacceptable.

Rationale (Dissolved oxygen):

Although information is available on the dissolved oxygen requirements of freshwater aquatic organisms, the requirements of marine organisms have not been studied as extensively, and specific information is quite sparse. The larvae of the clam (*Mercenaria mercenaria*) cannot tolerate oxygen levels below 4.0 mg/l, and additional experimentation indicates that it is essential to consider responses of developing eggs and larvae of marine species, as well as the juvenile and adult individuals (16, 17). However, information extrapolated from freshwater experimentation indicates that it is essential to consider responses of developing eggs and larvae of marine species, as well as the juvenile and adult individuals. Further, consideration must be given to the distribution of dissolved oxygen with increasing depth, since even under natural conditions low oxygen concentrations may be found in estuaries, where there are a reduction in salinity and increases in temperature over deeper open ocean waters.

3. Inorganics (Ions and Free Elements/Compounds)

a. Aluminum

The maximum acceptable aluminum concentrations in marine or estuarine waters and 1/100 (0.01) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of aluminum in excess of 1.5 mg/l in marine or estuarine waters are unacceptable.

Rationale (Aluminum):

Aluminum was reported (18) to be concentrated 15,000 times in benthic algae, 10,000 times in phytoplankton and zooplankton, 9,000 times in the soft parts of molluscs, 12,000 times in crustacean muscle, and 10,000 times in fish muscle. Because it tends to be concentrated by marine organisms, an application factor should be applied to marine 96-hour LC_{50} data. Except for some nonconclusive research (19, 20), specific work on the toxicity of aluminum compounds to marine organisms is sparse. However, aluminum hydroxide is known to have an adverse effect on bottom communities.

b. Antimony

The maximum acceptable concentration of antimony in marine or estuarine waters is 1/50 (0.02) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of antimony in excess of 0.2 mg/l in marine or estuarine waters are unacceptable.

Rationale (Antimony):

Few of the salts of antimony have been tested in bioassays, particularly on marine organisms. However, it is known that antimony can be concentrated by various marine organisms to more than 300 times the amount present in sea water (21). The average values of antimony from the world's oceans were reported to be 0.33 mg/l (22). Certain marine animals have revealed a tissue concentration of 0.2 mg/kg antimony (23).

c. Arsenic

The maximum acceptable concentration of arsenic in marine or estuarine waters is 1/100 (0.01) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of arsenic in excess of 0.05 mg/l in marine or estuarine waters are unacceptable.

Rationale (Arsenic):

Arsenic is normally present in sea water at concentrations of 2 to 3 ug/l and tends to be accumulated by oysters and other molluscan shellfish (18, 24). Concentrations of 100 mg/kg have been reported in shellfish (25). Arsenic is a cumulative poison with long-term chronic effects on both aquatic organisms and on mammalian species and a succession of small doses may add up to a final lethal dose (26).

d. Barium

The maximum acceptable concentration of barium in marine or estuarine waters is 1/20 (0.05) of the 96-hour LC_{50} value for the receiving water in question with the most important sensitive species in the locality as the test organism. Concentrations of barium in excess of 1.0 mg/l in marine or estuarine waters are unacceptable.

Rationale (Barium):

All water or acid-soluble barium coumpounds are poisonous. However, in sea water the sulfate and carbonate present tend to precipitate barium. The concentration of barium in sea water is generally accepted at about 20 ug/l (27).

Concentration factors for barium have been reported as 17,000 for phytoplankton, 900 for zooplankton, and 8 for fish muscle (18). Further, Russian marine radioactivity studies showed accumulation of radioactive barium in organs, bones, scales, and gills of fish from the Northeast Pacific (28).

e. Beryllium

The maximum acceptable concentration of beryllium in marine or estuarine waters shall not exceed 1/100 (0.01) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of beryllium in marine or estuarine waters in excess of 1.5 mg/l are unacceptable.

Rationale (Beryllium):

An application factor is required because of the accumulation of beryllium by marine organisms, its apparent toxicity to humans. The concentration of beryllium in sea water is 0.6 ug/l (3). It has been reported to be concentrated 1000 times in marine plants and animals (27). In addition, beryllium has been shown to inhibit photosynthesis in terrestrial plants (29); however, it is unknown if the same effect occurs in marine flora.

f. Bismuth

No level of acceptability for concentration of bismuth in marine or estuarine waters is prescribed.

Rationale (Bismuth):

There are no bioassay data on which to base criteria for bismuth. The concentration of bismuth in sea water is low, about 0.02 ug/l, probably because of the insolubility of its salts (3). It is unknown how much bismuth actually gets into the sea from man-made sources, but the quantity is probably small. Concentrations of 0.04 to 0.3 mg/l have been reported for marine animals, indicating concentration factors up to 10,000 (23).

g. Boron

The maximum acceptable concertration of boron in marine and estuarine waters is 1/10 (0.1) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism.

Rational (Boron):

Boron normally occurs in mineral deposits as sodium borate (borax) or calcium borate (colemanite). The concentration of boron in sea water is 4.5 mg/l (3). Available data on toxicity of boron to aquatic organisms are from fresh water; however, since the toxicity is slightly lower in hard water than in distilled water, it is anticipated that boric acid and borates would be less toxic to marine aquatic life than to freshwater organisms (3). An uncertainty exists concerning the effect of boron on marine vegetation. In view of the harm that can be caused to terrestrial plants by boron in excess of 1 mg/l (25), special precautions should be taken to maintain boron at ambient marine levels near kelp, eel grass, and other seaweed beds to minimize damage to these plants.

h. Bromine

The maximum acceptable concentration of free (molecular) bromine in marine and estuarine waters is 0.1 mg/l; further the maximum acceptable concentration of ionic bromine in the form of bromate in those waters is 100 mg/l.

Rationale (Bromine):

Ionic bromine is one of the major constituents in sea water, being present in concentrations of about 67 mg/l (3). Bromination of certain organic substances, such as phenols and amines, may impart offensive tastes and make waters more toxic to aquatic organisms. In one of the few experiments with bromine on marine organisms, a violent irritant response in marine fish was observed with a dose of 10 mg/l bromine, but no such activity was perceived at 1 mg/l (6).

i. Cadmium

The maximum acceptable concentration of cadmium in marine or estuarine waters is 1/100 (0.01) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. In waters known to have concentrations of copper and/or zinc in excess of 1 mg/l, the maximum application factor for cadmium is 1/1000 (0.001) of the 96-hour LC_{50} value. Concentrations of cadmium in marine or estuarine waters in excess of 0.01 mg/l are unacceptable.

Rationale (Cadmium):

Concern exists that cadmium may enter the diet, like mercury, through seafood. Cadmium, also like mercury, could form organic compounds which might be highly toxic or lead to mutagenic or teratogenic effects. Cadmium is known to have marked acute and chronic effects on aquatic organisms. American oysters (*Crassostrea virginica*) had an LD_{50} of 0.2 mg/l after 8 weeks exposure, but 0.1 mg/l after 15 weeks exposure (30).

Cadmium also acts synergistically with other metals. It inhibits shell growth in oysters (31), and low doses of cadmium (0.03 mg/l) in combination with zinc (0.15 mg/l) will kill chinook salmon fry (32). Killifish (*Fundulus heteroclitus*) exposed to 50 mg/l cadmium showed pathological changes in the intestinal tract after 1-hour exposure, and in the kidney after 12 hours (33). Copper and zinc, when present at 1 mg/l more, substantially increase the toxicity of cadmium (34). Cadmium is concentrated by marine organisms, particularly molluscs, which accumulate cadmium in calcareous tissues and in the viscera (35). A concentration factor of 1000 for cadmium in fish muscle has been reported (18), as have concentration factors of 3000 in marine plants, and up to 29,600 in certain marine animals (30).

j. Chromium

The maximum acceptable chromium concentrations in marine or estuarine waters is 1/100 (0.01) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of chromium in marine or estuarine waters in excess of 0.1 mg/l are unacceptable.

Rationale (Chromium):

Although most of the available information on toxicity of chromium is for freshwater organisms, a few experiments have been reported specifically for marine organisms. Because of the sensitivity of lower forms of aquatic life to chromium and its accumulation at all trophic levels, an application factor is required. Chromium concentrations in sea water generally have been reported between 0.04 and 0.4 mg/l (3, 36), but concentration factors of 1,600 in benthic algae, 2,300 in phytoplankton, 1,900 in zooplankton, 440 in soft parts of molluscs, 100 in crustacean muscle, and 70 in fish muscle have been reported (18). Chromium threshold toxicity levels of 1 mg/l for the polychaete *Nereis virens*, 5 mg/l for the prawn *Leander squilla*, and 20 mg/l for the crab *Carcinus maenus* have been reported (37). Chromium concentrations of 31.8 mg/l caused 100 percent mortality to coho salmon (*Oncorhynchus kisutch*) in sea water, with the time unspecified (38). A chromium concentration of 1 mg/l reduced photosynthesis by 10 to 20 percent in the giant kelp (*Macrocystis pyrifera*) after 5 days exposure (39).

k. Copper

The maximum acceptable concentration of copper (expressed as Cu) in marine and estuarine waters is 1/100 (0.01) of the 96-hour LC_{50} value determined by using the receiving water in question and the most important sensitive species in the locality as the test organism.
Concentrations of copper in marine or estuarine waters in excess of 0.05 mg/l are unacceptable.

Rationale (Copper):

Copper is present in sea water in concentrations ranging from 1 to 25 ug/l; however, the values are generally less than 3 ug/l (82). In small amounts, copper is nonlethal to aquatic organisms; in fact, it is essential for some respiratory pigments (25); however, it is accumulated by marine organisms, with concentration factors of 30,000 reported in phytoplankton, 5,000 in the soft tissues of molluscs, and 1,000 in fish muscle (18, 40). Copper is toxic to invertebrates, and because of this property it is used extensively in marine anti-fouling paints. Molluscs, particlarly, show great sensitivity to copper compounds. Two species of West Coast molluscs, _Acmaea scabra_ and _Haliotis fulgens_, when exposed to 0.1 mg/l copper show 100 percent mortality within 72 hours (41). Another mollusc, the mussel _Mytilus edulis_, showed 100 percent mortality at 0.14 mg/l copper within 24 hours (42). Work has also been done on the sensitivity of other molluscs to copper. Copper is toxic to oysters at low concentrations (25, 43, 44), although the toxicity apparently varies between species (45). Additionally, oysters exposed to concentrations of copper as low as 0.13 mg/l turn green in about 21 days (43), and although such concentrations of copper are neither lethal to the oysters nor harmful to man, green oysters are unmarketable because of their appearance. Thus, in the vicinity of oyster grounds, copper should not be introduced into areas where shellfish may become contaminated. Other marine invertebrates and plants have shown a sensitivity to copper compounds. The copepod *Arcartia clausi* when exposed to a dose of 0.5 mg/l copper, showed an LD_{50} within 13 hours (11). The tubeworm *Spirobis lamellosa*, also exposed to a dose of 0.5 mg/l copper, had an LD_{50} within 2 hours (46). Further, copper (in the form of the chloride and the sulfate) at concentrations of 0.1 mg/l inhibited photosynthesis of the giant kelp *Macrocystis pyrifera* by 70 percent within 48 hours (39). Finally, in studies of the sublethal effects of copper compounds on marine vertebrates, results have shown that Atlantic salmon (*Salmo salar*) will avoid copper concentrations as low as 0.0024 mg/l, indicating that an extremely sensitive copper-sensing mechanism is present in these fish (47, 48, 49).

1. Fluorides

The maximum acceptable concentration of fluorides in marine and estuarine waters is 1/10 (0.1) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of fluoride in excess of 1.5 mg/l in marine or estuarine waters are unacceptable.

Rationale (Fluorides):

There is virtually no information available on the effect of fluorides on marine organisms. The only data are from a study which indicates that the concentration of fluoride in the ocean occurs in two forms: approximately half as the unbound fluoride ion, F^-, with a range between 0.4 to 0.7 mg/l; the other fluoride component is bound as the double ion MgF^+, which has a similar concentration (50).

m. Iron

The maximum acceptable concentration of iron in marine and estuarine waters is 0.3 mg/l.

Rationale (Iron):

In the marine environment, iron is most often present either in organic complexes or in the ferric form adsorbed on particulate matter. However, because of the slightly alkaline condition of sea water much of the ferric form precipitates out (3). Thus, ferric hydroxide flocs may contaminate marine sediments, where commercially important invertebrate species, such as oysters, clams, scallops, lobsters, crabs or shrimp would be affected. Although damage to aquatic organisms is known from the smothering and coating action of these flocs, the evidence is available only from fresh water experimentation (10, 51-56). It is known, however, that iron is a necessary element in the formation of porphyrins, whose uptake may be either by ingestion of food or directly from the aquatic environment.

n. Lead

The maximum acceptable concentration of lead in marine or estuarine waters is 1/50 (0.02) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Further, the maximum acceptable 24-hour average concentration is 1/100 (0.01) of the 96-hour LC_{50}. Concentrations of lead in marine or estuarine waters in excess of 0.05 mg/l are unacceptable.

Rationale (Lead):

Certain marine plants have the ability to concentrate lead up to 40,000 times and certain marine animals up to 2,000 times (57). Very few experiments have been performed on the biological effects of lead on marine organisms. It has been found that lobsters died within 20 days when held in lead-lined tanks (20); the TLm for oysters (Crassostrea virginica), was found to be 0.5 mg/l lead when exposed for 12 weeks (30); and the 48-hour LC_{60} for Crassostrea virginica eggs was found to be 2.45 mg/l (57).

o. Manganese

The maximum acceptable concentration of manganese in marine or estuarine waters is 1/50 (0.02) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of manganese in excess of 0.1 mg/l in marine or estuarine waters are unacceptable.

Rationale (Manganese):

Manganese apparently has varying effects on lower trophic levels of aquatic organisms. Manganese concentrations of 5 ug/l have a toxic effect on certain freshwater algae (58), whereas 0.5 ug/l manganese (a decrease of only one order of magnitude) when added to marine diatom and flagellate cultures stimulated both their growth and reproduction rate (59). Further, in studies on the uptake of radionuclides in the area of the Pacific testing grounds at Bikini and Eniwetok, it was found that the radionuclide Mn 54 was concentrated as much as 4,000 times in phytoplankton and 12,000 times in the soft tissues of molluscs (18, 60).

p. Mercury

The maximum acceptable concentration of mercury in marine or estuarine waters is 1/100 (0.01) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of mercury in excess of 1.0 ug/l in marine or estuarine waters are unacceptable. Further, intentionally adding mercury to marine or estuarine waters is unacceptable.

Rationale (Mercury):

The behavior of mercury in the marine environment is not completely understood. Organo-mercurials are more highly concentrated by organisms than are inorganic mercury (61). It was found (62) that 82 percent of the mercury in Swedish marine fish was methylmercuric chloride. In addition to being biologically concentrated to a greater degree than inorganic mercury compounds, organo-mercurials are much more toxic than inorganic mercury to marine organisms (63). Nine mercuric salts and 23 organo-mercury compounds were tested (64) on the snail Australorbis glabratus; the most effective inorganic salt ($HgBr_2$) produced 80 percent mortality in 24 hours at 1 mg/l. Twelve organo-mercury compounds, on the other hand, produced significant mortalities at the 0.3 mg/l level. In many species of marine phytoplankton photosynthetic activity has been shown to be inhibited by a variety of mercury compounds (65). Vertebrate marine organisms have also experienced marked detrimental effects from mercury compounds. It was reported (66) that mercuric chloride drastically alters the cytological structure of the epithelium of the skin and gills in fish, and studies conducted on developing salmon eggs (*Oncorhynchus nerka* and *O. gorbuscha*) showed that concentrations of mercury at levels exceeding 3 ug/l mercury (derived from mercuric sulfate) led to severe deformities (67). Concentration factors have been reported to range from 200 for marine diatoms (68) to 10,000 for marine teleosts (69). Further, the acute toxicity of mercury to invertebrate marine organisms is high. Bivalve larvae were killed by 20 ug/l of mercuric chloride (70); copepods (*Acartia clausi*) were killed in 2.5 hours by 50 ug/l (71); 1.0 mg/l of mercuric chloride was lethal to adult barnacles (*Balanus balanoides*) within 48 hours (42); and the LD_{50} for tubeworm larvae (*Spirorbis lamellosa*) was found to be 0.14 mg/l in 2 hours (46).

q. Molybdenum

The maximum acceptable concentration of molybdenum in marine or estuarine waters is 1/20 (0.05) of the 96-hour LD_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism.

Rationale (Molybdenum):

Molybdenum has been found to be a needed micronutrient for the normal growth of phytoplankton (72); thus, it may play a vital role in the balance of ecosystems because of its requirement in algal physiology. Molybdenum concentrations for coastal marine waters range between 6 and 16 ug/l (973, 74, 75). It can be concentrated from 8 to 60 times by a variety of marine organisms including benthic algae, zooplankton, molluscs, crustaceans, and teleosts (18).

r. Nickel

The maximum acceptable nickel concentration in marine or estuarine waters is 1/50 (0.02) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of nickel in excess of 0.1 mg/l in marine or estuarine waters are unacceptable.

Rationale (Nickel):

Marine toxicity data for nickel are limited. It is known, however, that nickel ions are toxic, particularly to plant life, and may have increased toxicity when in the presence of other metallic ions. Nickel is present in coastal and open ocean concentrations in the range 0.1 - 6.0 ug/l, although the most common values are 2 - 3 ug/l. Marine animals contain up to 400 ug/l, and marine plants contain up to 3,000 ug/l (22). The lethal limit of nickel to sticklebacks has been reported as 0.8 mg/l (12); concentrations of 13.1 mg/l were reported to cause a 50 percent photosynthesis reduction in giant kelp (*Macrocystis pyrifera*) in 96 hours (39); and a concentration of 1.54 mg/l was found to be the LC_{50} value for eggs of the oyster (*Crassostrea virginica*) (57).

s. Phosphorus

The maximum acceptable elemental phosphorus concentration in marine or estuarine waters is 1/100 (0.01) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of the elemental phosphorus in excess of 0.1 ug/l in marine or estuarine waters are unacceptable.

Rationale (Phosphorus):

Phosphorus in the elemental form is particularly toxic and subject to bioaccumulation in much the same way as mercury (76, 77). Colloidal elemental phosphorus will poison marine fish causing surface discoloration resulting from hemolysis. Also, phosphorus is capable of being concentrated and will accumulate in organs and soft tissues. Experiments have shown that marine fish will concentrate phosphorus from water containing as little as 1 ug/l (78). In a series of experiments, the tissues of cod swimming in water containing 1 ug/l elemental phosphorus for 18 hours were analyzed. White muscle contained about 50 ug/kg, fat tissue about 150 ug/kg, and the liver 25,000 ug/l (78, 79).

t. Selenium

The maximum acceptable selenium concentration in marine or estuarine waters is 1/100 (0.01) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of selenium in excess of 0.01 mg/l in marine or estuarine waters are unacceptable.

Rationale (Selenium):

The concentration of selenium in open oceans has generally been reported as about 0.1 ug/l, with a range of 0.05 to 0.12 being the nominal values from the literature (22). In coastal waters, selenium values are generally higher; values of 0.25 ug/l for Puget Sound (80) and 4 - 6 ug/l (81) for the coastal areas of the Sea of Japan have been reported. There is no selenium bioassay information for marine species in the literature; however, selenium is known to be concentrated by some seaweeds (82).

u. Silver

The maximum acceptable silver concentration in marine or estuarine waters is 1/20 (0.05) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of silver in excess of 0.5 ug/l in marine or estuarine waters are unacceptable.

Rationale (Silver):

Silver is toxic to marine organisms and has been found to be concentrated by marine organisms by factors ranging from 80 for marine algae up to 1,000 for marine mammals (82). At 400 ug/l silver sulfate killed 90 percent of the barnacles (*Balanus balonoides*) tested in 48 hours (42). At concentrations of 100 ug/l, silver nitrate caused abnormal or inhibited development of eggs of the sea urchin *Paracentrotus* (83); concentrations of 2 ug/l delayed development and caused deformation of the resulting plutei. Adverse effects occurred at concentrations below 0.25 ug/l, and several days were required for recovery after placing the organisms in clean water. Detrimental effects on development of the sea urchin Arbacia due to silver nitrate have been reported at approximately 0.5 ug/l (25, 83).

In a study of the effects of silver salts on marine teleosts, it was reported (84) and generally supported (85) that the lethal concentration limit of silver nitrate for sticklebacks (Gasterosteus sp.) was 0.003 mg/l, with 0.0048 mg/l being the toxic threshold level. Also reported (86) were adverse effects on the liver enzymes of the killifish Fundulus heteroclitus resulting from 0.04 mg/l of silver. On a comparative basis, in studies on echinoderm eggs, silver has been found to be about 80 times as toxic as zinc, 20 times as toxic as copper and 10 times as toxic as mercury (83).

v. Thallium

The maximum acceptable thallium concentration in marine or estuarine waters is 1/20 (0.05) of the 20-day LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of thallium in excess of 0.1 mg/l in marine or estuarine waters are unacceptable.

Rationale (Thallium):

On the basis of very few observations, the concentration of thallium in open ocean waters is regarded as less than 0.01 ug/l. It is concentrated to some extent in giant kelp (Macrocystis pyrifera) (87), and there is one report of concentration factors of approximately 100 in marine invertebrates (88). There is no information on the effects of thallium compounds on marine organisms. It is known from freshwater experimentation, however, that thallium salts are cumulative and long-term poisons, and that the mode of action in fish and invertebrates appears to be as a neural poison (15). One response of fish to thallium poisoning is reported to be a rise in blood pressure (3).

w. Uranium

The maximum acceptable uranium concentration in marine or estuarine waters is 1/100 (0.01) of the 96-hr. LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of uranium in excess of 0.5 mg/l in marine or estuarine waters are unacceptable.

Rationale (Uranium):

Uranium is present at a concentration of approximately 3 ug/l in open ocean waters (3). Uranium salts, such as the sulfate, nitrate, and acetate, are soluble in water, and a significant proportion of these salts are in the form of stable complexes. It has been estimated that uranium compounds have residence times on the order of 3 million years in the oceans (27). This extremely slow turnover time is due to a hydrolytic stabilization which prevents physico-chemical interactions, and thus the removal of the compounds from sea water. There are no data on concentration of uranium compounds by marine organisms; further, the data on uranium toxicity to marine life are quite sparse. The data that are available suggest that uranyl salts are somewhat less toxic to marine than to freshwater organisms.

x. Vanadium

The maximum acceptable vanadium concentration in marine or estuarine waters is 1/20 (0.05) of the 96-hr. LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism.

Rationale (Vanadium):

The observed distribution of vanadium in offshore ocean waters has ranged between 1.8 and 7.0 ug/l (81, 89, 90). Vanadium is known to have been concentrated by certain marine forms during the formation of oil-bearing strata in the geologic past, and is one of the more common elements in organic sediments. Consequently, vanadium enters the atmosphere through the combustion of petroleum derivatives and then settles out on the oceans' surfaces (3). Certain marine invertebrate forms, such as tunicates, ascidians and several seaweeds, concentrate vanadium to a marked degree (89, 91). Whether any concentrations of vanadium are actually harmful to these marine invertebrates has not been demonstrated. There are no reports in the literature on the toxicity of vanadium to marine organisms. There is even a suggestion, however, that vanadium may be an essential micronutrient for all green plants (72).

y. Zinc

The maximum acceptable zinc concentration in marine or estuarine waters is 1/100 (0.01) of the 96-hr. LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of zinc in excess of 0.1 mg/l in marine or estuarine waters are unacceptable.

Rationale (zinc):

Observed values for the distribution of zinc in ocean waters vary widely. Values as high as 50 ug/l and as low as 3 ug/l have been reported for offshore ocean waters (92, 93). The major concern with zinc compounds in marine waters is not one of acute toxicity, but rather of the long-term sub-lethal effects of the metallic compounds and complexes. There is some information on the former, but solid data on the latter are sparse. From an acute toxicity point of view, invertebrate marine animals seem to be the most sensitive organisms tested. The growth of the sea urchin *Paracentrotus lividus* was retarded by as little as 30 ug/l of zinc (94); it was reported (46) that 4.9 mg/l of zinc citrate caused an LD_{50} in 2 hours for tubeworm larvae (*Spirorbis lamellosa*), and that 5.2 mg/l caused an LD_{50} in the same amount of time for bryozoan larvae (*Bugula neritina*). It was noted (42) that 32 mg/l of zinc nitrate was lethal to adult barnacles (*Balanus balanoides*) in 2 days, and that 8 mg/l was lethal in 5 days. Finally, 10 mg/l of zinc sulfate caused a 50 percent inactivation of photosynthesis in giant kelp (*Macrocystis pyrifera*) in 4 days (39). Concentrations of zinc have been reported as high as 1.5 g/l in marine animals (40), and concentration factors for zinc have been noted as high as 100,000 times in certain shellfish (95).

4. Organic Compounds

a. Cyanides

The maximum acceptable concentration of cyanides in marine or estuarine waters is 1/10 (0.1) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the locality as the test organism. Concentrations of cyanides in marine or estuarine waters in excess of 0.01 mg/l are unacceptable.

Rationale (Cyanides):

The majority of the available information on the toxicity of cyanides to aquatic organisms is for freshwater species; accordingly, discussion of these compounds is covered in the freshwater aquatic life criteria.

b. Oils

Concentrations of oil or petroleum products in marine or estuarine waters that exceed the limits described below are unacceptable.

a. Detectable as a visible film, sheen, discoloration of the surface, or by odor;

b. Causes tainting of fish or invertebrates or damage to the biota;

c. Forms an oil deposit on the shores or bottom of the receiving body of water.

Rationale (Oils):

Oil is one of the most widespread and serious contaminants of the world's oceans. Crude oils contain thousands of compounds, and differ markedly in their composition and in such physical properties as specific gravity, viscosity, and boiling-point distribution. The hydrocarbons in oil cover a wide range of molecular weights from 16 for methane to over 20,000 for the more complex compounds. Structurally, they include aliphatic compounds with straight and branched chains, olefins, and the aromatic ring compounds. In spite of their many differences, crude oils and their refined products all contain compounds that are toxic to marine organisms. It has been estimated that approximately 90 million tons of oil are entering the oceans from all sources every year (96). Most of this influx takes place in coastal regions, but oil slicks and tar balls have also been observed far out in open oceans (97). Although accidental oil spills are often spectacular events and attract the most attention, they constitute less than one percent of the oil entering the marine environment as a result of human activities (96). But when an oil spill occurs near shore, or is washed onto the intertidal zone beaches, extensive damage to marine organisms often occurs. An excellent example is a relatively small oil spill resulting from the grounding, in September 1969, of an oil barge off the Woods Hole Oceanographic Institution at West Falmouth, Massachusetts. Between 650 and 700 tons of No. 2 fuel oil were released into the coastal waters. Studies of the biological and chemical effects of this spill are continuing, more than two years after the event (98-101). Massive destruction of a wide range of fish, shellfish, worms, crabs, and other crustaceans and invertebrates occurred in the region immediately after the accident. Dredge samples taken in 10 feet of water soon after the spill showed that 95 percent of the animals recovered were dead and the others moribund. Much of the evidence of the immediate toxicity disappeared within a few days, either because of the breaking up of the soft parts of the organisms, burial in the sediments, or dispersal by water currents. Careful chemical and biological analyses reveal, however, that not only has the damaged area been slow to recover but the extent of the damage has been expanding with time. A year and a half after the spill, identifiable fractions of the source oil were found in organisms that still survived on the perimeter of the spill area. Although it is known that petroleum fractions can be degraded by marine microorganisms, very little is known about the mechanism of this degradation. However, it is known that no single microbial species can completely degrade any whole crude oil. Bacteria are highly specific, and several species are necessary to decompose the many types of hydrocarbons in a crude cil. Further, some of these interactions are restricted to aerobic conditions at the sea surface, while other degradation processes are anaerobic and occur only on those petroleum fractions that accumulate near the ocean bottom. In addition, the oxygen requirement of microbial oil decomposition is extremely large. The complete oxidation of only one gallon of crude oil requires all the dissolved oxygen in 320,000 gallons of air-saturated sea water (102). Further, the most readily attacked fraction of crude oil, the paraffins, is the least toxic; the more toxic aromatic hydrocarbons, especially the polynuclear aromatics, are not digested rapidly. There are only a few reputable observations on the specific toxicity of oil to marine organisms. Testing of eleven species of phytoplankton revealed that cell division was delayed or inhibited by concentrations of crude oil (unspecified types) as low as 0.01 mg/l (103). Earlier experimental results have shown 100 percent mortality of flounder fry at oil concentrations as low as 1 mg/l, and increased abnormal development in concentrations as low as 0.01 mg/l (104). It has been reported (105) that the Pacific coast sea urchin (Stronglycentrotus purpuratus) dies after a 1-hour exposure to 0.1 percent emulsion of diesel oil. In addition, crude oil adsorbed onto carbonized sand has been shown not to lose its toxicity (106). Three marine organisms were tested: toadfish embryos, barnacles, and a hydrozoan. Survival of the toadfish embryos varied from 13 days for a 0.5 percent concentration to 4 1/2 days for a concentration of 5 percent. The barnacles suffered a 90 percent mortality within 70 hours in a 2 percent mixture of oil in sea water, and the hydrozoans suffered a 100 percent mortality within 24 hours after being exposed to 0.5 percent oil-sand mixture. It should be noted that a sublethal effect, while not killing the organism directly, may render it less able to compete with individuals of the same species, and therefore may be as lethal *in toto* as a direct effect. It has also been shown that certain petroleum fractions block chemoreceptors in marine crustaceans which use chemoreception as a means of locating food (107) thereby placing them at a competitive disadvantage. At another level, specific petroleum fractions have been shown to interfere with reproduction of certain marine organisms (107). In the lobster, for example, reproductive success depends upon detection by the male of chemicals produced by the female known as pheramones, which are necessary to stimulate proper copulation in the species. Petroleum fractions mask the chemical activity of these pheramones, thereby preventing mating and reducing species fecundity.

5. Pesticides

The maximum acceptable concentration of pesticides in marine or estuarine waters is 1/100 (0.01) of the 96-hour LC_{50} value determined using the receiving water in question and the most important sensitive species in the area as the test organism.

Rationale (Pesticides):

The toxicity of ten chlorinated hydrocarbon pesticides and four organophosphorus insecticides to selected marine organisms is presented in Table 9, and the concentration of DDT found in various marine organisms is presented in Table 10. These tables are by no means complete, but they provide an idea of the great toxicity of the organic pesticides to marine organisms. For maximum concentrations of pesticides not in these tables, consult the freshwater criteria. In general, the substituted urea pesticides have been found to be the most toxic to marine organisms followed closely by the organo-mercurials. Although these two toxicants are not in such common use as some others, their toxicity is extreme. Following these two compounds in decreasing order of toxicity, it has been found that the chlorinated hydrocarbons are more toxic than the carbamate pesticides which are, in turn, generally more toxic than the organophosphates (108, 109, 110). In addition to the direct toxic action of pesticides on marine organisms, sublethal concentrations increase the physiological stress on organisms. This may reveal itself in decreased resistance to disease and parasites or decreased reproductive rates, longevity or general vigor. It was reported (111) that DDT interfered with the normal thermal acclimation mechanism of Atlantic salmon. Although DDT is one of the most ubiquitous toxicants in the marine environment, knowledge of its action is still quite rudimentary. However, it is known that despite its very low solubility in sea water it is concentrated at atmosphere-water and sediment-water interfaces (112, 113). Further, because of its high solubility in lipid-containing biological tissues, large concentration factors are encountered as trophic levels increase (114). Although it was reported (115) that concentrations of DDT occurred in the surface layers of Pacific coast sediments of at levels of only 0.040 mg/kg, DDT has been found in significant amounts in mesopelagic teleosts from depths of 9600 feet in the open ocean (116) and in concentrations of 1 part per thousand in marine mammals from the coast of California (115).

TABLE 9

Toxicity of various Pesticides to Selected Marine Organisms

ALDRIN

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Sand shrimp Crangon septemspinosa	8 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Oyster Crassostrea virginica	25 ug/l	LD_{50}	96 hrs.	Butler, 1964
Spot (Juvenile) Leiostomus xanthurus	5.5 ug/l	LD_{50}	48 hrs.	Butler, 1964
Hermit crab Pagurus longicarpus	33 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Grass shrimp Palaemonetes vulgaris	9 ug/l	LD_{50}	96 hrs.	Eisler, 1969

DDT

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Brine shrimp Artemia salina	12 ug/l	LD_{50}	5 hrs.	Tarpley, 1958
Sand shrimp Crangon septemspinosa	0.6 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Sheepshead minnow (Juvenile) Cyprinodon variegatus	5 ug/l	LD_{50}	48 hrs.	Butler, 1964
Spot (Juvenile) Leiostomus xanthurus	2 ug/l	LD_{50}	48 hrs.	Butler, 1964
Hermit crab Pagurus longicarpus	6 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Grass shrimp Palaemonetes vulgaris	2 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Dinoflagellate Peridinium trochoideum	10 ug/l	50% decrease in photosynthesis	24 hrs.	Wurster, 1968

TABLE 9 (cont.)

Toxicity of Various Pesticides to Selected Marine Organisms

DIELDRIN

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Sand shrimp *Crangon septemspinosa*	7 ug/1	LD_{50}	96 hrs.	Eisler, 1969
Spot (Juvenile) *Leiostomus xanthurus*	5.5 ug/1	LD_{50}	48 hrs.	Butler, 1964
Hermit crab *Pagurus longicarpus*	18 ug/1	LD_{50}	96 hrs.	Eisler, 1969
Grass shrimp *Palaemonetes vulgaris*	50 ug/1	LD_{50}	96 hrs.	Eisler, 1969

ENDRIN

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Sand shrimp *Crangon septemspinosa*	1.7 ug/1	LD_{50}	96 hrs.	Eisler, 1969
Spot (Juvenile) *Leiosotomus xanthurus*	0.6 ug/1	LD_{50}	48 hrs.	Butler, 1964
Hermit crab *Pagurus longicarpus*	12 ug/1	LD_{50}	96 hrs.	Eisler, 1969
Grass shrimp *Palaemonetes vulgaris*	1.8 ug/1	LD_{50}	96 hrs.	Eisler, 1969
Puffer fish *Sphaeroides maculatus*	3.1 ug/1	LD_{50}	96 hrs.	Eisler and Edmunds, 1966

TABLE 9 (cont.)

Toxicity of Various Pesticides to Selected Marine Organisms

HEPTACHLOR

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Sand shrimp *Crangon septemspinosa*	8 ug/1	LD_{50}	96 hrs.	Eisler, 1969
Spot (Juvenile) *Leiostomus xanthurus*	24 ug/1	LD_{50}	48 hrs.	Butler, 1964
Hermit crab *Pagurus longicarpus*	55 ug/1	LD_{50}	96 hrs.	Eisler, 1969
Grass shrimp *Palaemonetes vulgaris*	44 ug/1	LD_{50}	96 hrs.	Eisler, 1969

LINDANE

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Sand shrimp *Crangon septemspinosa*	5 ug/1	LD_{50}	96 hrs.	Eisler, 1969
Spot (Juvenile) *Leiostomus xanthurus*	30 ug/1	LD_{50}	48 hrs.	Butler, 1964
Hermit crab *Pagurus longicarpus*	5 ug/1	LD_{50}	96 hrs.	Eisler, 1969
Grass shrimp *Palaemonetes vulgaris*	10 ug/1	LD_{50}	96 hrs.	Eisler, 1969

TABLE 9 (cont.)

Toxicity of Various Pesticides to Selected Marine Organisms

METHOXYCHLOR

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Sand shrimp *Crangon septemspinosa*	4 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Spot (Juvenile) *Leiostomus xanthurus*	30 ug/l	LD_{50}	48 hrs.	Butler, 1964
Hermit crab *Pagurus longicarpus*	7 ug/l	LD_{50}	48 hrs.	Eisler, 1969
Grass shrimp *Palaemonetes vulgaris*	12 ug/l	LD_{50}	96 hrs.	Eisler, 1969

SEVIN

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Ghost shrimp *Callianassa californiensis*	0.13 mg/l	LD_{50}	24 hrs.	Stewart *et al* 1967
Dungeness crab (Juvenile) *Cancer magister*	0.60 mg/l	LD_{50}	24 hrs.	Stewart *et al* 1967
Cockle clam *Clinocardium nuttallii*	7.3 mg/l	LD 50	24 hrs.	Stewart *et al* 1967
Shiner perch (Juvenile) *Cymatogaster aggregata*	3.9 mg/l	LD 50	24 hrs.	Stewart *et al* 1967
3-spined stickleback *Gasterosteus aculeatus*	6.7 mg/l	LD 50	24 hrs.	Stewart *et al* 1967
Crab *Hemigrapsus oregonensis*	0.27 mg/l	LD 50	24 hrs.	Stewart *et al*

			1967	
English sole (Juvenile) *Parophrys vetulus*	4.1 mg/l	LD50	24 hrs. 1967	Stewart *et al*
Mud shrimp *Upogebia pugettensis*	0.4 mg/l	LD$_{50}$	48 hrs. 1967	Stewart *et al*

TABLE 9 (cont.)

Toxicity of Various Pesticides to Selected Marine Organisms

1-NAPHTHOL

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Ghost shrimp *Callianassa californiensis*	6.6 mg/1	LD_{50}	24 hrs.	Stewart *et al* 1967
Shiner perch (Juvenile) *Cymetogaster aggregata*	1.3 mg/1	LD_{50}	24 hrs.	Stewart *et al* 1967
3-spined stickleback *Gasterosteus aculeatus*	3.2 mg/1	LD_{50}	24 hrs.	Stewart *et al* 1967
Mud shrimp *Upogebia pugettensis*	4.4 mg/1	LD_{50}	48 hrs.	Stewart *et al* 1967

TOXAPHENE

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Spot (Juvenile) *Leiostomus xanthurus*	1 ug/1	LD_{50}	48 hrs.	Butler, 1964
Planktonic flagellate *Monochrysis lutheri*	0.015 ug/1	22% inhibition of growth	10 days	Ukeles, 1962
Planktonic diatom *Phaeodactylum tricornutum*	0.010 ug/1	46% inhibition of growth	10 days	Ukeles, 1962

TABLE 9 (cont.)

Toxicity of Various Pesticides to Selected Marine Organisms

MALATHION

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Sand shrimp *Crangon septemspinosa*	33 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Spot (Juvenile) *Leiostomus xanthurus*	55 ug/l	LD_{50}	48 hrs.	Butler, 1964
Hermit crab *Pagurus longicarpus*	83 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Grass shrimp *Palaemonetes vulgaris*	82 ug/l	LD_{50}	96 hrs.	Eisler, 1969

METHYL PARATHION

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Sand shrimp *Crangon septemspinosa*	2 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Hermit crab *Pagurus longicarpus*	7 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Grass shrimp *Palaemonetes vulgaris*	3 ug/l	LD_{50}	96 hrs.	Eisler, 1969

TABLE 9 (cont.)

Toxicity of Various Pesticides to Selected Marine Organisms

PARATHION

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Sheepshead minnow (Juvenile) Cyprinodon variegatus	60 ug/l	LD_{50}	48 hrs.	Butler, 1964
Brown shrimp Penaeus aztecus	1 ug/l	LD_{50}	48 hrs.	Butler, 1964

PHOSDRIN

Test Organism	Concentration of Toxicant	Effect on Organism	Duration of Exposure	Reference
Sand shrimp Crangon septemspinosa	11 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Sheepshead minnow (Juvenile) Cyprinodon variegatus	83 ug/l	LD_{50}	48 hrs.	Butler, 1964
Hermit crab Pagurus longicarpus	28 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Grass shrimp Palaemonetes vulgaris	69 ug/l	LD_{50}	96 hrs.	Eisler, 1969
Brown shrimp Penaeus aztecus	250 ug/l	LD_{50}	96 hrs.	Butler, 1964

TABLE 10

DDT Concentrations in Fish

Geographic Region	Material Tested	Concentration in mg/kg
Open North Atlantic	Pelagic fish muscle	0.6 - 3
	Pelagic fish liver	95 - 4800
	Midwater fish and crustacea	3 - 12
Open South Atlantic	Midwater fish and crustacea	1 - 8
Denmark Straits	Groundfish muscle	3 - 30
	Groundfish liver	390 - 2600
Gulf of Mexico	Fish muscle	3 - 30
Northeast Pacific	Euphausiids	2.7 (mean)
	Pink shrimp	2.5 (mean)
	Flatfish	10.8 (mean)
West Coast of Scotland	Fish muscle	30 - 480
	Fish liver	70 - 5800
Baltic Sea	Herring muscle	100 - 1500
	Cod muscle	9 - 340

Source:(3)

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6. Radioactivity

The acceptable levels of radionuclides in sea water are those concentrations which are sufficiently small that the concentration in any marine organism harvested for human consumption will not cause total radionuclide ingestion by the most exposed group using the food to exceed that prescribed in Federal Drinking Water Standards. If the consumption of these foodstuffs is so widespread that it is likely that the aggregate dose to the exposed population will exceed 3000 man-rem per year, limitations on the distribution and sale should be considered by the relevant public health authorities.

Rationale (Radioactivity):

These criteria are based on the prudent assumption that radiation levels in marine food organisms which are acceptable for human consumption will not injure the marine organisms themselves (121). Man-made radioisotopes were not released into the environment until 1944, when the first atomic bomb was tested. Prior to that time, all radiation in marine waters occurred from natural sources. Of this naturally-occurring radiation in sea water, greater than 90 percent is from the isotope potassium-40. During the last 30 years, however, the principal source of radionuclides in the oceans has been nuclear weapons testing. While the release of radioisotopes was drastically reduced with the cessation by the major powers of atmospheric weapons testing, radioactive waste continues to be released to the oceans from nuclear powered ships and submarines and from nuclear power and fuel reprocessing plants (122). It is difficult to measure the amount of radiation affecting marine organisms because they are simultaneously irradiated by radioisotopes within their body from previously consumed organisms, by radioisotopes adsorbed on the surface of their body from the water, and by radioisotopes in sediments. Nevertheless, it is known that radioisotope concentration factors can be quite large. Average concentration factors for significant radionuclides as cited in a recent NAS monograph may be as high as 5,000 for benthic algae, 50,000 in phytoplankton, 25,000 in zooplankton, 2,500 in crustacean muscle, and 1,600 for fish muscle (123). The edible fraction of shellfish may bioconcentrate manganese and zinc on the average of 12,000 and 11,000 times respectively. The biological effects of radioactivity adsorbed and absorbed by marine organisms may be damaging at both the cellular and molecular levels. Damage to the organism may include developmental abnormalities, physiologic changes, inhibition of growth, behavioral changes, shortening of life span, or finally, death. In addition, synergistic biological damage from radiation may be induced by environmental stresses such as changes in temperature or salinity. Furthermore, irradiation can cause gross pathological changes which are easily observed, or it can result in more subtle changes which are difficult or impossible to detect. In addition to somatic changes which affect the individual, genetic changes also may occur which may affect the offspring for many generations. Bacteria and algae may tolerate doses of many thousands of rads. The LD_{50} (lethal dose for 50 percent mortality in 30 days) for marine fish is one thousand to a few thousand rads. As expected, eggs and early developmental stages are more sensitive than are adults. By comparison, the mean lethal whole-body dose from a single short exposure to humans is about 300 rads (3).

7. Temperature

Maximum acceptable water temperature increases are 2.2 C (4.0°F) during the months of September through May, or 0.8°C (1.5°F) during the months of June through August.

WHEN SUFFICIENT INFORMATION ON MARINE SPECIES BECOMES AVAILABLE, TEMPERATURE CRITERIA FOR MARINE WATERS WILL BE THE SAME AS FRESHWATER.

Rationale (Temperature):

The single most important variable to marine organisms is temperature, and the literature contains much information on both direct and indirect effects of temperature increases on marine organisms, particularly teleosts. Included in the marine temperature rationale that follows are exemplary citations from the literature on the direct and indirect effects of temperature changes and maximum temperature levels. A temperature increase may affect the marine organism directly, by changing physiologic or behavioral processes, or it may affect organisms indirectly, by changing some aspect of the environment on which the organism depends. The cause of thermal death in marine fishes has been variously attributed to synapse failure at myoneural junctions (124), thermal denaturation of body cells, inactivation of cholinesterase (126), and to coagulation in the bronchial capillaries (127). For example, it was found (128) that to produce heat death in the killifish (Fundulus heteroclitus) required 63 minutes at 34°C (93.2°F), 28 minutes at 36°C (96.8°F), 9 minutes at 37° C (98.6°F), and only 2 minutes at 42°C (107.6°F). It is recognized that consideration must be given to whether the organism has been acclimatized to the warmer temperatures during the experimentation or if it has been suddenly exposed to them, resulting in heat death by shock. It is reported (129) that most marine teleosts do not survive above 33°C (91.4°F). For polar species, the median upper lethal limit is 26°C (78.8°F), for species inhabiting temperate ocean waters, that same limit is 30°C (86°F); and while insufficient data are available to project a median, upper lethal limit for tropical marine species, it is known that these fish are already living so close to their thermal death points that a rise of even a few degrees may cause severe mortalities (129). It was demonstrated, for example (130), that tropical marine fishes have extremely small thermal tolerances. Experimentation showed that pelagic larvae of ten species of tropical Indian Ocean fish would survive only between 27°C (80.6°F) and 30°C (86°F). The larvae of temperate marine fish are also sensitive to rapid changes in temperature (131). As would be expected, the eggs, larvae, and juvenile forms of marine fishes are far more sensitive than adult forms to temperature changes. Part of this sensitivity may be the result of a lack of ability to metabolically compensate for the temperature changes. It has been found that sea lamprey (Petromyzon sp.) eggs will not hatch above 31°C (87°F) (133) and chinook salmon (Oncorhynchus sp.) eggs will not hatch above 16.5°C (61.7°F) (134). These egg mortalities were attributed to failures in gastrulation, in melanophore formation, and in initiation of circulation. Other experiments on the eggs of a Pacific marine fish (Clinocottus) revealed (135) that as the temperature was increased from 22°C (71.6°F) to 24°C (75.2°F), the percentage of gastrulated eggs dropped from more than 70 percent to less than 5 percent, and the percentage of hatched embryos dropped from 75 percent to zero. Although sublethal temperatures may not kill outright, they may produce, through heat stress, other physiologic aberrations. A loss of swimming ability in fish, due in large part to a significant increase in mucous production over the body was reported (136). Without such a vital ability a fish is likely to be unable to capture its food, escape its predators, or avoid environmental dangers, either natural or man-made. Other physiological aberrations due to heat stress that have been reported are a partial failure of osmoregulation in Pacific cottid fishes (137), and increased oxygen consumption; the latter was reported in the eel (Anguilla) (138), in the killifish (Fundulus) (139), and in the cunner (Tautogolabrus) (140). Increased oxygen consumption with increased temperatures is particularly critical to fishes, since as water temperature increases, oxygen solubility decreases, thereby increasing the potential for mortality. Temperature increases also affect the rate of color change in marine fishes. The ability to change from tan to black decreased (141) in the plaice (Pleuronectes) at temperatures above 16°C (60.8°F); a loss of pigment in Pacific killifish (Fundulus parvipinnis) at high temperatures was reported (142); also reported (143) was the fact that the Atlantic salmon (Salmo salar) did not dark-adapt as well at high temperatures (20°C) (68°F) as they did at normal temperatures 5°C (41°F). Though sublethal in nature, these temperature effects could affect the survival of the organism, since avoidance of predators is often dependent upon the ability to color adapt. High sublethal temperatures also exert detrimental effects on growth rates in marine fish. In experiments where fish were subjected to high sublethal temperatures for extended periods of time (136), the amount of food consumed by the test organisms was several times that of the controls. Despite this increased food consumption, the test fish became emaciated. In addition, increased water temperatures offer improved media for the growth, reproduction, and rate of infestation and infection of parasites and disease. A run of sockeye salmon (Oncorhynchus nerka) was nearly obliterated due to the combined effects of high temperature and bacterial infection (126). It was reported from examination of the literature that most fish diseases are favored by increased water temperatures (144). Using salmon under experimental conditions, it was found that higher water temperatures drastically increased the severity of kidney disease, vibric (a skin lesion disease), furunculosis (a blood vessel and muscle degenerative disease), and columnaris (a skin and muscle degenerative disease (144). In the Delaware River estuary a high incidence of deformed fins in striped bass (Roccus saxatilus) was reported (145) which was attributed to heated effluents from a nearby power generating plant. Finally, heated effluents from an electric power plant in California were deliberately directed toward a nearby beach to warm the sea water for bathers and surfers. However, the plan has had its drawbacks; the beach must be closed periodically to seine out the large sharks attracted by the warm waters.

B. Wildlife

1. General

Except for the specific harmful substances addressed below, the marine aquatic life criteria are acceptable for application to coastal and marine waters inhabited by wildlife. The freshwater wildlife criteria are in general acceptable for application to estuarine wildlife.

Rationale (General):

Marine wildlife refers to those species of mammals, birds and reptiles which inhabit estuaries or coastal and marine waters for at least a portion of their life span. Although fish, invertebrates and plankton are not considered to be wildlife, they constitute the food web upon which the wildlife species depend for their subsistence. Consequently, the criteria for marine wildlife necessarily include all criteria formulated to protect the fish, invertebrate and plant communities.

1. Specific Harmful Substances

a. DDT and Derivatives

The maximum acceptable concentrations of DDT in any sample consisting of a homogenate of 25 or more whole fish of any species that is consumed by fish-eating birds and mammals, within the size range consumed, is 50 mg/kg on a wet weight basis. DDT residues are defined as the sum of the concentration of p,p -DDT, p,p -DDD, p,p -DDE and their ortho-para isomers (3).

Rationale (DDT and Derivatives):

DDT compounds are widespread and locally abundant pollutants in coastal and marine environments of North America. The most abundant of these is DDE 2,2-bis (p-chlorophenyl) dichloroethylenel , a derivative of the insecticide DDT compound, p,p -DDT. DDE is more stable than other DDT derivatives, and very little information exists on its degradation in ecosystems. Except for sediment deposition, no degradation pathway has been shown to exist in the sea (3). Experimental studies have shown that DDE induces shell thinning of eggs of birds of several families, including Mallard Ducks (*Anas platyrhynchos*) (146), American Kestrels (*Falco sparverius*) (147), Japanese Quail (*Coturnix*) (148) and Ring Doves (*Streptopelia risoria*) (149). Studies of eggshell thinning in wild populations have reported inverse relationship between shell thickness and concentrations of DDE in the eggs of Herring Gulls (*Larus argentatus*) (150), Double-crested Cormorants (*Phalacrocorax auritus*) (151), Great Blue Herons (*Ardea herodias*) (152), White Pelicans (*Pelecanus erythrorhynchos*) (151), Brown Pelicans (*Pelecanus occidentalis*) (153, 154), and Peregrines (*Falco peregrinus*) (155) (See 3). Because of its position in the food web, the Peregrine accumulates higher residues than fish-eating birds in the same ecosystem (156), and is considered to be the species most sensitive to environmental residues of DDE (3). The most severe cases of shell thinning documented to date have occurred in the marine ecosystem of southern California (157) where DDT residues in fish have been in the order of 1-10 mg/kg of the whole fish (154). In Connecticut and Long Island, shell thinning of eggs of the Osprey (*Pandion haliaetus*) is sufficiently severe to adversely affect reproductive success; over North America, shell thinning of Osprey eggs also shows a significant negative relationship with DDE concentration (See 3). DDT residues in collections of eight species of fish from this area in 1970 ranged from 0.1 to 0.5 mg/kg of the wet weight (158). Evidently this level of contamination is higher than one which would permit the successful reproduction of several of the fish-eating and raptorial birds (3).

b. Aldrin, Dieldrin, Endrin, and Heptachlor

The maximum acceptable sum of the concentrations of aldrin, dieldrin, endrin and heptachlor epoxide in any sample consisting of a homogenate of 25 or more whole fish of any species that is consumed by fish-eating birds and mammals, within the size range consumed, is 5.0 mg/kg on a wet weight basis.

Rationale (Aldrin, Dieldrin, Endrin and Heptachlor):

Aldrin, dieldrin, endrin and heptachlor constitute a class of closely related, highly toxic, organochlorine insecticides. Aldrin is readily converted to dieldrin in the environment, and heptachlor to the highly toxic derivative, heptachlor epoxide. Like the DDT compounds, dieldrin may be dispersed through the atmosphere (159, 156). The greatest hazard of dieldrin exists to fish-eating birds such as the Bald Eagle (*Haliaeetus leucocephalus*) (160), Common Egret (*Casmerodius albus*) (161 and to the Peregrine (*Falco peregrinus*) (162), which may accumulate lethal amounts from fish or birds which are not themselves harmed (See 3). These compounds are somewhat more soluble in water than are other chlorinated hydrocarbons such as the DDT group (163); partition coefficients between water and fish tissues can be assumed to be lower than those of the DDT compounds. Equivalent concentrations in fish would therefore indicate higher environmental levels of dieldrin, endrin or heptaclor epoxide than of DDE or any of the other DDT compounds. Moreover, these compounds are substantially more toxic to wildlife than are other chlorinated hydrocarbon pesticides (3).

c. Other Chlorinated Hydrocarbons

The maximum acceptable concentration of chlorinated hydrocarbon insecticides including lindane, chlordane, endosulfan, methoxychlor, mirex, toxaphene and hexchlorobenzene, in any sample consisting of a homogenate of 25 or more whole fish of any species that is consumed by fish-eating birds and mammals, within the size range consumed is 50 mg/kg on a wet weight basis.

Rationale (Other Chlorinated Hydrocarbons):

Other chlorinated hydrocarbon insecticides include lindane, chlordane, endosulfan, methoxychlor, mirex, and toxaphene. Hexachlorobenzene is likely to have increased use as a fungicide as mercury compounds are phased out. This compound is toxic to birds and is persistent (164). With the possible exception of hexachlorobenzene, recommendations that protect the invertebrate and fish life of estuaries from injudicious use of these pesticides will also protect the wildlife species. In the light of the experience with DDT and dieldrin, the large scale use of a compound such as mirex can be expected to have adverse effects on wildlife populations.

d. Polychlorinated Biphenyls (PCB's)

The maximum acceptable concentrations of PCB in any sample consisting of a homogenate of 25 or more whole fish of any species that is consumed by fish-eating birds and mammals, within the size range consumed is 0.5 mg/kg on a wet weight basis.

Rationale (PCB):

Evidence is accumulating that PCB does not contribute to the shell thinning that has been a major symptom of the reproductive failures and population declines of raptorial and fish-eating birds (3). A PCB effect could not be associated with the thinning of Brown Pelican (*Pelecanus occidentalis*) eggshells (165) nor did dietary PCB produce any effect on the eggs of Mallard Ducks (*Anas platyrhynchos*) (166) or Ring Doves (*Streptopelia risoria*) (167). PCB may increase susceptibility to infectious agents such as virus diseases (168) and like other chlorinated hydrocarbons PCB increases the activity of liver enzymes that degrade steroids, including sex hormones (156, 169). Laboratory studies have indicated that PCB, with its derivatives or metabolites, causes embryonic death of birds (170, 171, 172, 173). Because exceptionally high concentrations are occasionally found in fish-eating and raptorial species (156, 174), it is highly probable that PCB has had an adverse effect on the reproductive capacity of some species of birds that have shown population declines (3). Median PCB concentrations in whole fish of eight species from Long Island Sound, obtained in 1970, were in the order of one mg/kg (158), and comparable concentrations have been reported from southern California (175). On the basis of the high probability that PCB in the environment has contributed to the reproductive failures of fish-eating birds, it is desirable to decrease these levels by at least a factor of two (3).

Marine Water Constituents

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VII. RECREATIONAL WATERS

A. Aesthetic Considerations

1. Aesthetics - General

a. All surface waters should be capable of supporting life forms of aesthetic value.

b. Surface waters should be "free" of substances attributable to discharge or wastes as follows:

(1). Materials that will settle to form objectionable deposits;

(2). Floating debris, oil, scum, and other matter;

(3). Substances producing objectionable color, odor, taste, or turbidity;

(4). Materials, including radionuclides, in concentrations or combinations (which are toxic or) which produce undesirable physiological responses in humans, fish and other animal and plant life; and

(5). Substances and conditions or combinations thereof in concentrations which produce undesirable aquatic life.

Rationale (Aesthetic Considerations):

Aesthetic criteria are to be applied in the context of local conditions and are intended in general terms to provide for the protection of surface waters from substances which tend or might tend to degrade the aesthetic quality of water. The use of the term "free" recognizes the practical impossibility of complete absence and inevitability of the presence of potential pollutants to some degree.

2. Nutrient (Phosphorus)

No limit of acceptability is prescribed for phosphorus (P) in recreational waters.

Rationale (Phosphorus):

Acceptable limits for phosphorus in receiving waters where it is a limiting constituent for nuisance aquatic plant growths are believed to be:

Water Body	Maximum Phosphorus (P) Concentration
Within lakes and reservoirs	25 ug/l
At a point where a river enters a lake or reservoir	50 ug/l
Flowing streams	100 ug/l

Reducing phosphorus in lakes and reservoirs is the single most important step that can be taken in the control of eutrophication at this time (1, 2, 3, 4). It is recognized that the phenomenon of eutrophication is complex and that there may be waterways wherein higher concentrations of total phosphorus do not produce eutrophy, as well as those waterways wherein lower concentrations of total phosphorus may be associated with populations of nuisance organisms. Waters now containing less than the specified amount of phosphorus should not be degraded by the introduction of additional phosphates. Exceptions to the above stated limits need to be recognized in any water management program. Because of naturally occurring poor quality or because of technological limitations in the control of introduced pollutants, some waters may not meet the desired levels. This determination must be made on a case-by-case basis following an analysis of available data and conditions associated with each such area. There are situations where higher levels of phosphorus than those above can be tolerated by the waterway without developing biological nuisances or increasing the threat of eutrophication. Often naturally-occurring phenomena limit the development of such nuisances. Examples include those waters highly laden with natural silts or colors which reduce the penetration of sunlight needed for plant photosynthesis, those waters whose morphometric features of steep banks, great depth, and substantial flows contribute to a history of no plant problems, or those waters that are managed primarily for waterfowl or other wildlife.

B. Recreational Waters

1. Clarity

For bathing and swimming waters, clarity should be such that a Secchi disc is visible at a minimum depth of 4 feet and visible on the bottom in areas designated as "learn to swim". Acceptable clarity in diving areas the clarity is equal to the minimum required by safety standards depending upon the height of the diving board or platform.

Rationale (Clarity):

Clarity is important for recreational waters for a variety of reasons among which are safety, visual appeal and recreational enjoyment. Absolute criteria are impossible since local conditions vary. However, turbidity due to human activities should be controlled in recreational areas.

2. Microorganisms

a. Bacteriological Indicators

1). The indicator organisms for contamination of surface waters by potential human pathogens are the fecal coliform group of bacteria.

2). Without reference to official designation of recreation as a water use, surface waters are, as a minimum, to be suitable for human recreation where there is little significant risk of ingestion. In the absence of local epidemological experience an average of 2000 fecal coliforms per 100 ml and a maximum of 4000 per 100 ml, except in specified mixing zones adjacent to outfalls, shall not be exceeded for such waters.

3). In waters designated for recreation where the whole body may be completely submerged or there is significant probability of ingestion, the maximum acceptable limit for fecal coliform content is the log mean of 200 per 100 ml, and not more than 10 percent of total samples during any 30-day period are to exceed 400 per 100 ml. This is to be determined by multiple-tube fermentation or membrane filter procedures and based upon a minimum of not less than five samples for any 30-day period of the recreation season.

Rationale (Bacteriological Indicators):

Fecal coliforms are used as an indicator group since they have been shown to originate from warm blooded animals and their presence in water indicates the potential presence of human pathogenic bacteria and viruses. The use of fecal coliforms as the indicator group is supported by the fact that approximately 95 percent of the total coliform organisms in the feces of birds and mammals yield positive fecal coliform tests and a similar portion of the total coliform organisms in uncontaminated soils and plant material yield negative fecal coliform tests (5). A fecal coliform level of 2000 per 100 ml is intended to provide for the enjoyment of limited contact users in relative safety. Such use includes boating, fishing and other non-whole-body immersion activities incident to shoreline usage. Whole-body immersion recreation refers to those activities such as bathing, swimming and water skiing in which there is prolonged and intimate contact with the water with considerable risk of ingesting water in quantities sufficient to pose a significant health hazard. As fecal coliform levels increase, there is a greater probability that human pathogens, such as Salmonella, also increase. The fecal coliform level of 200 was chosen since this number is compatible with data which indicate low probability of enteric pathogen concentrations (6, 7, 8).

b. Viruses

No limits are prescribed for viruses in recreational waters.

Rationale (Viruses):

Although considerable progress in the area of virological methodology has been made in the past years, no method useful in routine monitoring has been perfected. Also, data on die-off rates, correlation with existing indicators and selection of a significant indicator virus are not available. For these reasons no indicator virus or limits are prescribed, even though it is clearly recognized that viruses of fecal or other human origin may present a health hazard when contaminating recreational waters.

3. pH

In bathing and swimming waters, the acceptable range of pH is 6.5 to 8.3 except where due to natural causes and in no case less than 5.0 or more than 9.0.
Rationale (pH):

Natural waters are usually alkaline or acidic and may cause eye irritation because the pH is unfavorable. Hence special requirements for whole-body submersion recreation waters are more strict than those established for other areas. In light of its coordinate effect, the buffering capacity requires considerations in criteria to prevent eye irritation. The lacrimal fluid of the human eye is approximately 7.0 (9) and a deviation of 0.1 pH unit from the norm may result in eye irritation (10). Appreciable irritation will cause severe pain (9).

4. Shellfish

Species available for harvest by recreation users are to be fit for human consumption. In areas where taking of mollusks is a recreational activity, the criteria are to be consistent with the current edition of the U.S. Public Health Service Manual, "Sanitation of Shellfish Growing Areas".

Rationale (Shellfish):

The intent here is to protect persons engaged in recreational shellfishing. Consideration shall be given to factors affecting shellfish growing such as; microbiological quality, pesticides, marine biotoxins, trace metals and radionuclides. The recreation harvester shall be afforded the same level of protection as the consumer of commercial products and therefore the criteria of the U.S. Public Health Service is governing.

5. Temperature

Except where caused by natural conditions, water temperatures of bathing and swimming waters in excess of 30 C°(86 °F) are not acceptable.

Rationale (Temperature):

Excessively high temperatures are damaging to aquatic biota and present a risk to the swimmer (6). High temperatures limit body heat dissipation and may, through elevation of the deep body temperature, produce physiological disturbance (5).

References: Recreational Waters

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APPENDIX A

FISH TEMPERATURE DATA SHEETS

Species in Alphabetical Order

Fish Temperature Data Sheet

Species (common & scientific name) Atlantic salmon (Salmo salar)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source 3/
Upper	5			22.2		1
	6		22.0			1
	10			23.3		1
	20			23.5		1

*30 days after hatch

Lower						

Growth: 1/	larvae	juvenile	adult	
optimum		15.6-18.3		4
range 2/				

Preferred (final):	larvae	juvenile	adult	
summer	14°* (2)	17(5)	13.6-16.2(6)	2,5,6
winter				

*when acclimated to 4°C

Gonad development: Requires (x)

Low winter temp.	X*	Temp.	Period	7
Some winter decrease		Temp.	Period	
No winter decrease		Temp.	Period	

*12°C precludes gonad development

Spawning: Optimum ______ Range 2/ 4.4-5.6 (9) Dates Oct-Dec 8.9

Hatch of normal larvae: Optimum ______ Range 2/ 0.5 - 7.2°C. 3

Migration: adults 23°C or less, smolt 10°C or less 7

Habitat:

Spawning	Stream riffles	8
Substrate	gravel	8

Larvae: Planktonic ____ Pelagic ____ Demersal ____

Juvenile	Freshwater lakes (landlocked strain) Ocean and tributary streams	
Adult	Freshwater lakes (landlocked strain) Ocean and tributary streams	

1/ Net growth - Growth in wt. minus wt. of mortality

2/ As reported or to 50% of optimum if data permit

3/ list sources on back of page in numerical sequence.

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Atlantic salmon

References

1. Bishal, H. M. 1960. Upper lethal temperatures for larval salmonids. Jou. Du Conseil 25(2):129-133.

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Fish Temperature Data Sheet

Species (common & scientific name) Bigmouth buffalo (*Ictiobus cyprinellus*)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper						
Lower						

Growth:[1]	larvae	juvenile	adult	
optimum				
range[2]				

Preferred (final):	larvae	juvenile	adult	
summer				
winter				

Gonad development: Requires (x)

		Temp.	Period	
Low winter temp.				
Some winter decrease				
No winter decrease				

Spawning: Optimum 16.7 Range[2] 14.4-26.7 Dates late April into June 1,2,3,4,8

Hatch of normal larvae: Optimum ______ Range[2] 13.9-16.7 2,7,8

Habitat:

Spawning in shallow calm, mud-bottomed areas with vegetation, ditches, small streams 5,6,4,8

Substrate mud and vegetation

Eggs randomly broadcast, adhesive, 4-14 days to hatch 1,2,4,8

Larvae: Planktonic ____ Pelagic ____ Demersal ____

Juvenile Same as adult

Adult Shallow, turbid, overflow ponds, oxbows, lowland lakes, deep pools of rivers and streams 5,1

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[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

Bigmouth buffalo

References

1. Johnson, R. P., 1963. Studies on the life history and ecology of the bigmouth buffalo, Ictiobus cyprinellus (Valenciennes). J. Fish. Res. Bd. Canada 20:1397-1429.

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Fish Temperature Data Sheet

Species (common & scientific name) Black crappie (Promoxis nigromaculatus)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source3/
Upper						
	29			32.5*		2

*upper incipient lethal

Lower						

Growth:1/	larvae	juvenile	adult	
optimum		22-25		2
range2/		11-30*		2

*limits of zero growth

Preferred (final):	larvae	juvenile	adult	
summer	18-20*(6)		median 28 24-34(1)	1,6
winter				

*surface water temp. when larvae appeared in limnetic waters in Wis.

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___

Some winter decrease ___ Temp. ___ Period ___

No winter decrease ___ Temp. ___ Period ___

Spawning: Optimum ___ Range2/ 14.4-17.8(4)* Dates Mar (4)-July (3) 3,4

*begin spawning

Hatch of normal larvae: Optimum ___ Range2/ ___

Habitat:

Spawning	Nests in shallow water 1-2' on sand or gravel (3);	3
	sometimes on muddy bottoms (5)	5
	Substrate See spawning	
Larvae:	Planktonic ___ Pelagic ___ Demersal ___	
Juvenile		
Adult	Lakes, reservoirs, slow streams; in areas containing	7
	vegetation and submerged objects; less tolerant to turbidity than white crappie	

1/ Net growth - Growth in wt. minus wt. of mortality

2/ As reported or to 50% of optimum if data permit

3/ list sources on back of page in numerical sequence.

Black crappie

References

1. Neill, W. H., J. J. Magnuson and G. G. Chipman. 1972. Behavioral thermoregulation by fishes - new experimental approach. Science 176 (4042:1443).

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Fish Temperature Data Sheet

Species (common & scientific name) Bluegill (Lepomis macrochirus)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source 3/
Upper	15(2), 12.1(8)			27.5(8)	30.5(2)	2,8
	20				32	2
	25(2), 26(8)			36.1(8)	33(2)	2,8
	30				33.8	2
	32.9(8)			37.3(8)		8
Lower	15(2), 12.1(8)			3.2(8)	2.5(2)	2, 8
	20				5.0	2
	25(2), 26(8)			9.8(8)	7.5(2)	2,8
	30				11	2
	32.9(8)			15.3(8)		8

Growth: 1/	larvae	juvenile	adult	
optimum			22	3,4
range 2/			15.6-26.7	1

Preferred (final):	larvae	juvenile	adult	
summer		32.3		9
winter				

Gonad development: Requires (x)

Low winter temp. ____ Temp. ____ Period ____ ________

Some winter decrease ____ Temp. ____ Period ____ ________

No winter decrease probable Temp. ____ Period ____ 10

Spawning: Optimum 28(7) Range 2/ 19.4(5)-32.2(6) Dates April, June - late Aug. 1

Hatch of normal larvae: Optimum 22.2-23.9(8) Range 2/ 21.9-33.9(8) 8

Habitat:

Spawning Nest in sand, gravel, dead leaves, sticks or mud in shallow water (2-6' depth common) 1

Substrate see spawning

Larvae: Planktonic ____ Pelagic X Demersal several days 11

Juvenile See adult

Adult Ponds, lakes, sluggish streams with vegetation and sand, gravel or muck bottom 1

1/ Net growth - Growth in wt. minus wt. of mortality

2/ As reported or to 50% of optimum if data permit

3/ list sources on back of page in numerical sequence.

Bluegill sunfish

References

1. Emig, J. W. 1966. Bluegill sunfish. In: Inland Fisheries Mgt. A. Calhoun ed. , Calif. Dept. Fish and Game.

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Fish Temperature Data Sheet

Species (common & scientific name) Brook trout (Salvelinus fontinalis)

Lethal threshold:	Acclimation temperature	embryo	alevin ~~larvae~~	juvenile	adult	Data source3/
Upper	3				23.5	3
	11				24.6	3
	12		20.1*	24.5**(2)		2
	15				25.0	3
	20				25.3	3
	25				25.3	3
Lower						
				Near freezing		4

*Newly hatched
**Swimup

Growth:1/	larvae	juvenile	adult	
optimum	12.4-15.4(2)		16 (1)	1,2
range2/	7-18 (2)		10-19 (1)	1,2

Preferred (final):	larvae	~~juvenile~~	~~adult~~	
summer		Age not stated		5
winter		14-19°C		

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___

Some winter decrease ___ Temp. ___ Period ___

No winter decrease ___ Temp. ___ Period ___

Spawning: Optimum <9 Range2/ ? - 11.7 Dates Sept-Nov 1

Hatch of normal larvae: Optimum 6 Range2/ -12.7 1

Habitat:

Spawning Rivers and streams; when these are not available springs have been reported as satisfactory alternatives.

Substrate Gravel in riffles and heads or trails of pools

Larvae: Planktonic ___ Pelagic ___ Demersal ___

Juvenile Streams with temperatures not exceeding 20°C and lakes a little warmer, but with cooler water available 6

Adult

1/ Net growth - Growth in wt. minus wt. of mortality

2/ As reported or to 50% of optimum if data permit

3/ list sources on back of page in numerical sequence.

Brook trout

References

1. Hokanson, K.E.F., J. H. McCormick, B. R. Jones, and J. H. Tucker. 1973. Thermal requirements for maturation, spawning, and embryo survival of the brook trout, Salvelinus fontinalis (Mitchill). J. Fish. Res. Bd. Canada, 30(7):975-984.

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Fish Temperature Data Sheet

Species (common & scientific name) Carp (Cyprinus carpio)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper	20			31-34 (24 hr. TL_{50})		4
	26			35.7 (24 hr. TL_{50})		4
Lower						

Growth:[1]	larvae	juvenile	adult	
optimum				
range[2]				
Preferred (final):	**larvae**	**juvenile**	**adult**	
summer		31-32 (Acc. 25-35)		7
winter		17 (Acc. 10)		7

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___ ___

Some winter decrease ___ Temp. ___ Period ___ ___

No winter decrease ___ Temp. ___ Period ___ ___

Spawning: Optimum 20* Range[2] 16(5)-26(2) Dates Mar-Aug(6) 2,5,6

*estimated

Hatch of normal larvae: Optimum ___ Range[2] 16.7 - 22 6,8

Abnormal larvae after 35°C shock of embryos 1

Habitat:

Spawning Adhesive eggs broadcast in shallow areas usually less than 1 ft. deep 2,5

Substrate mud in association with vegetation 2

Larvae: Planktonic ___ Pelagic ___ Demersal X 2

Juvenile low gradient, warm streams; lakes, reservoirs or overflow sloughs, oxbows that contain an abundance of organic matter; shallow water in summer, deeper water in winter. 3,2

Adult Same as juveniles

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[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

Carp

References

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Fish Temperature Data Sheet

Species (common & scientific name) Channel catfish (Ictalurus punctatus)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper	15°C		31.0(3)*		30.4(2)	2,3
	25			35.5 (1)	33.5(2)	1,2
	30			≈37.0 (1)		1
	35			38.0 (1)		1

*temperature of max. survival; acclimation temperature not given

Lower	15				0.0	2
	20				0.0	2
	25				0.0	2

Growth:[1]	larvae	juvenile	adult	
optimum	29-30 (3)	30(4)		3,4
range[2]	27-31 (3)	≈ 22-34 (4)		3,4

Preferred (final):	larvae	juvenile	adult	
summer				
winter				

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___ ___

Some winter decrease ___ Temp. ___ Period ___ ___

No winter decrease probable Temp. 22.8 Period in Fla. Constant 10 temp. springs

Spawning: Optimum 26.7 (5) Range[2] 21.1-29.4 (5) Dates Mid April - late July (7) Missouri 5,7

Hatch of normal larvae: Optimum 21.7 (9) Range[2] 18.3(8) - 29.4(5) 5,8,9

Habitat:

Spawning	Usually semi-dark nests under logs, rocks overhanging banks and other protected areas	6
Substrate		
Larvae:	Planktonic ___ Pelagic ___ Demersal ___	
Juvenile	Bottom waters, riffles	11
Adult	bottom waters, deep holes and riffles for feeding	11

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[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

Channel catfish

References

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Fish Temperature Data Sheet

Species (common & scientific name) Cisco (lake herring) (Coregonus artedii)

Lethal threshold:	Acclimation temperature	early embryo ≈ 10° C	larvae	juvenile	adult	Data source3/
						1
	3		19.8			2
Upper	2 (3)			19.8(3)	20(4,6)*	3,4,6
	5(3) <10(5)			21.8(3)	<24(5)	3,5
	>12.5*			26.0	*no	3
	20			26.3	acclim.	3
	25 *ultimate upper lethal			25.8	temp. given	3
	2			<0.3		3
Lower	5			<0.5		3
	10			3.0		3
	20			4.8		3
	25			9.8		3

Growth:1/	larvae	juvenile	adult	
optimum	16			2
range2/	13-18			2

Preferred (final):	larvae	juvenile	adult	
summer			≈13	6
winter				
avoidance			>15.5 - >17	6,7

Gonad development: Requires (x)

Movement onto spawning grounds ≈5°C 7

Low winter temp. ___ Temp. ___ Period ___ ___

Some winter decrease ___ Temp. ___ Period ___ ___

No winter decrease ___ Temp. ___ Period ___ ___

Spawning: Optimum ≈3.5 Range2/ 1.1-5.0 Dates Mid Nov.-Mid Dec. 7,8,9

Hatch of normal larvae: Optimum ≈10 Range2/ 2 - 8 1

Hatching period Apr-May, Lake Ontario (9), Early May Lake Superior (10) 9,10

Habitat:

Spawning Over shoals and along shore, from 1 to 160 m of water depth. Usually <50 m. 8

Substrate Some say substrate not important; others say over flat stones, fine rubble to boulders, free of vegetation 7,8,9

Larvae: Planktonic X Pelagic ___ Demersal ___ 9,11
In protected bays

Juvenile ___

Adult Below the 20°C isotherm and above the 2.5-3.0 ppm D.O. isopleth. 4

1/ Net growth - Growth in wt. minus wt. of mortality

2/ As reported or to 50% of optimum if data permit

3/ list sources on back of page in numerical sequence.

Cisco

References

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Fish Temperature Data Sheet

Species (common & scientific name) Coho salmon (Oncorhynchus kisutch)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3/]
Upper	5			22.9		1
	10			23.7	21*(3)	1,3
	15			24.3		1
	20			25.0		1
	23			25.0		1
					*acclim. temp. unknown	
Lower	5			0.2		1
	10			1.7		1
	15			3.5		1
	20			4.5		1
	23			6.4		1

Growth:[1/]	larvae	juvenile	adult	
optimum		20*		2
range[2/]		10-15		5
		*maximum with excess food		

Preferred (final):	larvae	juvenile	adult	
summer				
winter			12.8	4

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___ ___

Some winter decrease ___ Temp. ___ Period ___ ___

No winter decrease ___ Temp. ___ Period ___ ___

Spawning: Optimum ______ Range[2/] 7.2-12.8(3) Dates Fall ______ 3

Hatch of normal larvae: Optimum ______ Range[2/] ______

Migration and maturation range 7.2-15.6(5). 5

Rearing areas: range 10.0 - 15.6(3) 3

Habitat:

Spawning Migrates up streams, spawns typically near the head of riffles 6

Substrate gravel 6

Larvae: Planktonic ___ Pelagic ___ Demersal ___

Juvenile Rivers, migrating to ocean or lake

Adult Sea or large lakes; rivers during migration and spawning

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[1/] Net growth - Growth in wt. minus wt. of mortality

[2/] As reported or to 50% of optimum if data permit

[3/] list sources on back of page in numerical sequence.

Coho salmon

References

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Fish Temperature Data Sheet

Species (common & scientific name) Emerald Shiner (Notropis atherinoides)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source 3/
Upper	5			22-23.2		1
	10			26.7-27		1
	15			28.9		1
	20			30.7-31		1
	25			30.7		1
	Ultimate			30.7		1
	≈ 31			24 hr TL_{50} 32.6°C(2)		2
Lower						
	15			1.6		1
	20			5-5.2		1

Growth: 1/	larvae	juvenile	adult	
optimum		29 (2)		2
range 2/		24-31 (2)		2

Preferred (final):	larvae	~~juvenile~~ (unknown age)	~~adult~~	
summer		25 (3)		3
winter		27 (4)		4

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___

Some winter decrease ___ Temp. ___ Period ___

No winter decrease ___ Temp. ___ Period ___

Spawning: Optimum 23* Range 2/ 20 (3) - 27.5 (7) Dates May-Aug (1) (5) 1,3,5,7

*Estimated from field reports

Hatch of normal larvae: Optimum ___ Range 2/ ___

Habitat:

Spawning Open water near surface over 2 to 6 meters of water (3) 3

Substrate ___

Larvae: At surface in warm water (5) ~~Planktonic~~ ___ ~~Pelagic~~ ___ ~~Demersal~~ ___ 5

Juvenile In spring found where warmest water is present (3) 3

Adult ___

1/ Net growth - Growth in wt. minus wt. of mortality

2/ As reported or to 50% of optimum if data permit

3/ list sources on back of page in numerical sequence.

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Emerald shiner

References

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2. McCormick, J. H. and C. F. Kleiner. 1970. Effects of temperature on growth and survival of young-of-the-year emerald shiners (*Notropis atherinoides*). Unpublished data, National Water Quality Laboratory, Duluth, Minnesota.

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Fish Temperature Data Sheet

Species (common & scientific name) Freshwater drum (Aplodinotus grunniens)

Lethal threshold:

	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper						
Lower						

Growth:[1]

	larvae	juvenile	adult	
optimum				
range[2]				

Preferred (final):

	larvae	juvenile	adult	
summer				
winter				

Gonad development: Requires (x)

Low winter temp.		Temp.	Period	
Some winter decrease		Temp.	Period	
No winter decrease		Temp.	Period	

Spawning: Optimum 21.1 Range[2] 18.9(1)-24.4 Dates early May-late June (1) 1,2,3,5,8

Hatch of normal larvae: Optimum ______ Range[2] 22.2-25.6(1) 1,4,8

Habitat:

Spawning Probably open water 8

Substrate ______

eggs - pelagic, hatch in about 24-36 hrs. 4,3,1.8

Larvae: Planktonic ______ Pelagic X Demersal ______ 4

Juvenile On bottom of lakes and deep pools of rivers and large reservoirs 6,7

Adult Same as juveniles

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[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

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Freshwater drum

References

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7. Trautman, M. B. 1957. Fishes of Ohio. Ohio State Univ. Press.

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Fish Temperature Data Sheet

Species (common & scientific name) Largemouth bass (Micropterus salmoides)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper	20°C			32.5		1
	25			34.5		1
	30			36.4		1
	35			36.4		1
Lower	20			5.2		1
	25			7.0		1
	30			10.5		1

Growth:[1]	larvae	juvenile	adult	
optimum	27.5			2
range[2]	20 - 30			2
Preferred (final):	larvae	juvenile	adult	
summer		30 - 32.2*		8
winter				

*Season not given

Gonad development: Requires (x)

Low winter temp.		Temp.	Period		
Some winter decrease	X	Temp. to 15.6	Period	Aug.- Nov.	4 (Florida)
No winter decrease	X	Temp. 21.0	Period	Oct.- Apr.	7

Spawning: Optimum 21(4) Range[2] 15.6-26.7(4) Dates Apr-June (North) (3) Nov-May (Florida)(4) 3.4

Hatch of normal larvae: Optimum 20(5) Range[2] 12.8-23.9 (6) 5.6

Habitat:

Spawning	Six inches to 6 feet depth, usually 2-2 1/2' Nests often inconspicuous	10
Substrate	Sand, gravel, detritus, vegetation, roots	10
Larvae:	Planktonic ___ Pelagic X Demersal 1st 5-8 days	3
Juvenile	Non-flowing vegetated waters	9
Adult	Inactive below 10°C, do not feed at 5°C	9

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[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

Largemouth bass

References

1. Hart, J. S. 1952. Geographic variations of some physiological and morphological characters in certain freshwater fish. Univ. Toronto Biological Series No. 60.

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Fish Temperature Data Sheet

Species (common & scientific name) Northern pike (*Esox lucius*)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper	17.7		25,28.4*			2
	25			32.2		1
	27			32.7		1
	30			33.2**		1

*At hatch and free swimming, respectively

**Ultimate incipient lethal

Lower	17.7		3.2*			2

*At hatch and free swimming

Growth:[1]	larvae	juvenile	adult	
optimum	20.8	26		2
range[2]	18 - 25.6			2
Preferred (final):	larvae	juvenile	adult	
summer		24, 26*		7
winter				

*Grass pickrel and musky, respectively

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___ ______

Some winter decrease ___ Temp. ___ Period ___ ______

No winter decrease ___ Temp. ___ Period ___ ______

Spawning: Optimum ______ Range[2] 4.4(4)-18.5(3) Dates Feb-June (5) 3,4,5

Hatch of normal larvae: Optimum 12 Range[2] 6.9 - 19.2 2

Habitat:

Spawning Marshy areas along lakes and streams or connected sloughs (6); shallow water, usually <12 inches (4) 4,6

Substrate Vegetation 6

Larvae: Planktonic ___ Pelagic ___ Demersal Several days 6

Juvenile Spawning areas (temporarily) and shallow water 6

Adult Lakes and streams with vegetation

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[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

Northern pike

References

1. Scott, D. P. 1964. Thermal resistance of pike (Esox lucius L.) muskellunge (E. masquinongy, Mitchell) and their F_1 hybrid. J. Fish. Res. Bd. Canada 21:1043-1049.

2. Hokanson, K.E.F., J. H. McCormick and B. R. Jones. 1973. Temperature requirements for embryos and larvae of the northern pike, Esox lucius (Linnaeus). Trans. Amer. Fish. Soc. 102:89-100.

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Fish Temperature Data Sheet

Species (common & scientific name) Rainbow trout (Salmo gairdneri)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper						
	18			26.5		1
	19				21	2
Lower						

Growth:[1]	larvae	juvenile	adult	
optimum		17-18.5°		5
range[2]				

Preferred (final):	larvae	juvenile	adult	
summer		13.6*		3
winter				

*season not given

Gonad development: Requires (x)

Low winter temp.	___	Temp. ___	Period ___	
Some winter decrease	___	Temp. ___	Period ___	
No winter decrease	___	Temp. ___	Period ___	

Spawning: Optimum ________ Range[2] 5.5-13.0(6) Dates Nov.-Feb. (7) Feb.-June (7) 6,7

Hatch of normal larvae: Optimum ________ Range[2] 5.6-13.3(4) 4

Habitat:

Spawning Streams, rarely in lakes 4

Substrate gravel

Larvae: Planktonic ___ Pelagic ___ Demersal in part (7) 7

Juvenile Streams, lakes

Adult Streams, lakes

Steelhead - Ocean, large lakes

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[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

Rainbow trout

References

1. Alabaster, J.S. and R. L. Welcomme. 1962. Effect of concentration of dissolved oxygen on survival of trout and roach in lethal temperatures. Nature, Lond. 194(4823), 107-.

2. Coutant, C. C. 1970b. Thermal stress of adult coho (*Oncorhynchus kisutch*) and jack chinook (*O. tshawytscha*) salmon, and the adult steelhead trout (*Salmo gairdnerii*) from the Columbia River. AEC BNWL 1508.

3. Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada, 15:607-624.

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Fish Temperature Data Sheet

Species (common & scientific name) Sauger (Stizostedion canadense)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3/]
Upper	9-21		75-92%*			8
			*survival			
Lower	6		0%*			8
			*survival			

Growth:[1/]	larvae	juvenile	adult	
optimum				
range[2/]				

Preferred (final):	larvae	juvenile	adult	
summer			18.6-19.2*	2
winter			*field	

Gonad development: Requires (x)

Low winter temp. ___ Temp. ____ Period ____

Some winter decrease ___ Temp. ____ Period ____

No winter decrease ___ Temp. ____ Period ____

Spawning: Optimum 10(7)* *approx. In Tenn. Range[2/] 5.6(1) - 14.4(3) Dates Apr-May(3)(1) 1, 3, 7

Hatch of normal larvae: Optimum 12-15* *Max. egg survival Range[2/] 10-16* *egg survival >50% 8

Habitat:

Spawning Shallow gravelly or sandy areas along shore or in tributary streams 4

Substrate ____

Larvae: Planktonic ____ Pelagic ____ Demersal ____

Juvenile ____

Adult Large clean lakes and streams preferred in Mn(5) 5

More turbid lakes and streams than Walleye in Ohio (6) 6

[1/] Net growth - Growth in wt. minus wt. of mortality

[2/] As reported or to 50% of optimum if data permit

[3/] List sources on back of page in numerical sequence

Sauger

References

1. Nelson, W. R. 1968. Reproduction and early life history of sauger, Stizostedion canadense, in Lewis and Clark Lake. Trans. Amer. Fish. Soc. 97:167-174.

2. Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada. 15:607-624.

3. Hall, G. E. 1972. Personal communication, TVA.

4. Fish, M. P. 1929a and 1929b. In: Breder, C. M. and D. E. Rosen, 1966. Modes of reproduction in fishes. Natural History Press.

5. Eddy, S. and T. Surber. 1947. Northern fishes. Univ. Minn. Press.

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Fish Temperature Data Sheet

Species (common & scientific name) Smallmouth bass (Micropterus dolomieui)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper			38.0(9)*			9

*acclimation temperature not given

Lower	15 (3)		4.0(9)*	1.6(3)		3,9
	18			3.7		3
	22			6.7		3
	26			10.1		3

*acclimation temperature not given

Growth:[1]	larvae	juvenile	adult	
optimum	28-29 (2)	26.3 (3)		2,3
range[2]				
	30 = best swimming speed (9)			9

Preferred (final):	larvae	juvenile	adult	
summer			21.1-26.7(6) highest 28.0(4)*	4,6
winter			>7.8**	1

*season & life stage unknown

**life stage unknown

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___ ______

Some winter decrease ___ Temp. ___ Period ___ ______

No winter decrease ___ Temp. ___ Period ___ ______

Spawning: Optimum 16.7-17.8(5) Range[2] 13(8)-21.1(7) Dates May-July (Ontario) (5) 5,7,8

Hatch of normal larvae: Optimum ______ Range[2] ______ ______

Habitat:

Spawning	Shallow water; slight current, if any; near shore or stream bed; during day	8
	Substrate gravel, rock	8
	Deserts nests on sharp drop to below 15 (7)	7
Larvae:	Planktonic ___ Pelagic ___ Demersal X	7
Juvenile	Streams with riffles and pools	6
	Lakes with moderate vegetation	
Adult	Same as juvenile	

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[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

Smallmouth bass

References

1. Munther, G. L. 1968. Movement and distribution of smallmouth bass in the Middle Snake River. Master's Thesis, Univ. Idaho.

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Fish Temperature Data Sheet

Species (common & scientific name) **Smallmouth buffalo, (Ictiobus bubalus)**

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper						
Lower						

Growth:[1]	larvae	juvenile	adult	
optimum				
range[2]				

Preferred (final):	larvae	juvenile	adult	
summer				
winter				

Gonad development: Requires (x)

Low winter temp. ___ Temp. ____ Period ____ __________

Some winter decrease ___ Temp. ____ Period ____ __________

No winter decrease ___ Temp. ____ Period ____ __________

Spawning: Optimum 16.7(1)(5) Range[2] 13.9(1)-23.9 Dates late Mar (1) thru June 1,4,5

Hatch of normal larvae: Optimum __________ Range[2] 13.9(1)-21.1 1,5

Habitat:

Spawning In shallow, calm, mud bottomed areas with vegetation, ditches, small streams 1,2,6

Substrate mud and vegetation

egg: randomly broadcast, adhesive 2,5,6

Larvae: Planktonic _____ Pelagic _____ Demersal _____

Juvenile Shallow overflow ponds, oxbows, lowland lakes, deep pools of rivers and streams, less turbid waters than that frequented by bigmouth buffalo 3

Adult Same as juveniles

[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

Smallmouth buffalo

References

1. Wrenn, W. B. 1969. Life history aspects of smallmouth buffalo and freshwater drum in Wheeler Reservoir, Alabama. Proc. 22nd Ann. Conf. S. E. Assoc. Game & Fish Comm., 1968. pp. 479-495.

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Fish Temperature Data Sheet

Species (common & scientific name) Sockeye salmon (Oncorhynchus nerka)[a]

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper	5			22.2		1
	10			23.4		1
	15			24.4		1
	20			24.8		1
Lower	5			0		1
	10			3.1		1
	15			4.1		1
	20			4.7		1
	23			6.7		1

Growth:[1]	larvae	juvenile	adult	
optimum	15(6)	15*(2)		2,6
range[2]		10-15 *maximum with excess food		5

Preferred (final):	larvae	juvenile	adult	
summer		14.5		3
winter				

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___

Some winter decrease ___ Temp. ___ Period ___

No winter decrease ___ Temp. ___ Period ___

Spawning: Optimum ___ Range[2] 7.2-12.8 Dates Fall 10

Hatch of normal larvae: Optimum ___ Range[2] 5.8-12.8 4

Migration and maturation: 7.2 - 15.6 5

Migration halted: 21 9

Habitat:

Spawning Migrates only up streams having lakes in the system, spawns in shallow waters of lakes and in tributary streams 7

Substrate Gravel 7

Larvae: Planktonic ___ Pelagic ___ Demersal ___

Juvenile Start sea-ward migration before temperatures reach 14-15°C 8

Adult Sea, rivers and lakes during migration and spawning

[a] Data pertains to sea-run sockeye, not kokanee

[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

Sockeye Salmon

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Fish Temperature Data Sheet

Species (common & scientific name) Striped bass (Morone saxatilis)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source 3/
Upper						
Lower						

Growth: 1/	larvae	juvenile	adult	
optimum				
range 2/				

Preferred (final):	larvae	juvenile	adult	
summer				
winter				

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___ ______

Some winter decrease ___ Temp. ___ Period ___ ______

No winter decrease ___ Temp. ___ Period ___ ______

Spawning: Optimum 16.7 - 19.4 Range 2/ 12.8-21.7 Dates Apr-July 1,2,3,4,5

Hatch of normal larvae: Optimum ______ Range 2/ 15.6-23.9 1

Habitat:

Spawning In freshwater rapids in association with rocks and boulders. Eggs are semi-buoyant and must be suspended by currents or other turbulence for 30-80 days required for hatching 2,3,4,5

Substrate ______ ______

Larvae: Planktonic X Pelagic ___ Demersal ___ 3

Juvenile In rivers and estuaries until 2 years old and then migrate to ocean. 2

Adult Ocean and estuaries (some landlocked). Anadromous Return after spawning 2,6

1/ Net growth - Growth in wt. minus wt. of mortality

2/ As reported or to 50% of optimum if data permit

3/ list sources on back of page in numerical sequence

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Striped bass

References

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Fish Temperature Data Sheet

Species (common & scientific name) Threadfin shad (Dorosoma petenense)

Lethal threshold:

	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper						
				Winter (field)		
Lower					3.8	1
					5	2
					7.2	3
	Chronic exposure below 9°C detrimental [2]					2

Growth:[1]	larvae	juvenile	adult	
optimum				
range[2]				

Preferred (final):	larvae	juvenile	(age not given) adult	
summer			>19.5	4
winter				

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___

Some winter decrease ___ Temp. ___ Period ___

No winter decrease ___ Temp. ___ Period ___

Spawning: Optimum ___ Range[2] 14-21(5)(6) Dates Apr-Aug(6)(11) 5,6,11

Hatch of normal larvae: Optimum ___ Range[2] 23-26(8) 16.7-26.7(9) 8,9

Habitat:

Spawning Under brush and floating logs (6); also in open water. 6

Repeated spawnings throughout the summer with a 2nd pulse in fall

XXXXXXXXXX when conditions are right 11,7

XXXXXXX Planktonic ___ Pelagic ___ Demersal ___

XXXXXXXXX Age of fish not given - Pelagic, limnetic zone 10

Adult

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[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

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Threadfin shad

References

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Fish Temperature Data Sheet

Species (common & scientific name) White bass (Morone chrysops)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source 3/
Upper						
Lower	17.2		14.4*			3

* % mortality not given

Growth: 1/	larvae	juvenile	adult	
optimum		22.6-23.6*		5
range 2/				

*good growth in S. Dak. reservoir

Preferred (final):	larvae	juvenile	adult	
summer				
winter				

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___ ______

Some winter decrease ___ Temp. ___ Period ___ ______

No winter decrease ___ Temp. ___ Period ___ ______

Spawning: Optimum ______ Range 2/ 14.4-23.9 (North) 11.7 (Tenn) Dates April-July (North) Mar-May (Tenn.) 1

Hatch of normal larvae: Optimum 15.6 - 16.7 Range 2/ ______ 2

Habitat:

Spawning Tributary streams or shoals of lakes; shallow water (<10 feet); eggs adhesive 1

Substrate gravelly or rocky bottom, usually 1

Larvae: Planktonic ___ Pelagic X Demersal ___ 6

Juvenile Shallows near shore 4

Adult Rivers and lakes; tolerate wide range of physical and chemical conditions 4

1/ Net growth - Growth in wt. minus wt. of mortality

2/ As reported or to 50% of optimum if data permit

3/ list sources on back of page in numerical sequence.

White bass

References

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Fish Temperature Data Sheet

Species (common & scientific name) White crappie (*Pomoxis annularis*)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper						
				32.6*		5

*upper incipient lethal

Lower						

Growth:[1]	larvae	juvenile	adult	
optimum		25		5
range[2]				

Preferred (final):	larvae	juvenile	adult	
summer			22-27	1
winter				

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___

Some winter decrease ___ Temp. ___ Period ___

No winter decrease ___ Temp. ___ Period ___

Spawning: Optimum ___ Range[2] 16-20(6) 17.8-20(4)* Dates Mar (4)- July (3) 3,4,6

*begin spawning

Hatch of normal larvae: Optimum ___ Range[2] ___

Hatch in 24-27-1/2 hrs. at 21.1-23.3° 2

Habitat:

Spawning Nests near brush, stumps, rock, often on plant material 4

Substrate ___

Larvae: Planktonic ___ Pelagic ___ Demersal ___

Juvenile ___

Adult Lakes, reservoirs, slow streams, in areas containing vegetation and submerged objects; more tolerant of turbidity than the black crappie 7

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[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

White crappie

References

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Fish Temperature Data Sheet

Species (common & scientific name) White sucker (Catostomus commersoni)

Lethal threshold:

	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3/]
Upper	5			26(2)		2
	10		28.1(1)*	28(2)		1,2
	15	21(1)	30.7(1)	29.3(2)		1,2
	20(2), 21(1)		30.5(1)	29.3(2)		1,2
	25			29.3(2)		2
	25-26			31.2		3

*7-day TL_{50} for swimup

	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3/]
Lower	15	8.5[1/]				1
	20			2.5-3.0		2
	25			6.0		2
	21		6.1*			1

*7 day TL_{50} for swimup

Growth:[1/]	larvae	juvenile	adult	
optimum	27			1
range[2/]	24-27			
				1

Preferred (final):	larvae	juvenile	adult	
summer			19-21	4
winter				

Gonad development: Requires (x)

Low winter temp. ___ Temp. ___ Period ___

Some winter decrease ___ Temp. ___ Period ___

No winter decrease ___ Temp. ___ Period ___

Spawning: Optimum ~ 10(5) Range[2/] ~4.5-18*(5,6) Dates Mar-June(2) 2,5,6

Hatch of normal larvae: Optimum 15 Range[2/] 8-21 1

*field estimates, limits not known

Habitat:

Spawning Along wave swept shores, or when available, up tributary streams over gravel riffles. 5

Substrate sand and/or gravel 1

Larvae: At surface in quiet water until the mouth becomes inferior whereupon demersal life begins. ~~Planktonic~~ ___ ~~Pelagic~~ ___ ~~Demersal~~ ___

Juvenile Over sandy shoals, near shore, on the bottom 7, 8

Adult Pools of streams and rivers;off shore above thermocline in lakes, but demersal, moving inshore during the evening and night. 9, 10,11

1/ Net growth - Growth in wt. minus wt. of mortality

2/ As reported or to 50% of optimum if data permit

3/ list sources on back of page in numerical sequence.

White sucker

References

1. McCormick, J. H., B. R. Jones, and K.E.F. Hokanson. 1972. Effects of temperature on incubation success and early growth and survival of the white sucker, *Catostomus commersoni* (Lacepede). Unpublished data, National Water Quality Laboratory, Duluth, Minnesota.

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Fish Temperature Data Sheet

Species (common & scientific name) Yellow perch (*Perca flavescens*)

Lethal threshold:	Acclimation temperature	embryo	larvae	juvenile	adult	Data source[3]
Upper	5				21.3	1
	11(1), 9.8(6)		9.8(6)*		25(1)	1,6
	15(1), 18.8(6)		18.8(6)*		27.7(1)	1,6
	25				29.7*	1
	25				32.3**	1
			*swim-up	*winter incipient lethal **summer incipient lethal		
Lower	25			3,7		1

Growth:[1]	larvae	juvenile	adult	
optimum				
range[2]			≈13(9) - ≈20(10)	9,10

Preferred (final):	larvae	juvenile	adult	
summer		24.2		2
winter		22.2* (11) *spring	21.0(2)	2,11

Gonad development: Requires (x)

Low winter temp.	X	Temp. 4.0	Period 6 mo.	5
Some winter decrease		Temp.	Period	
No winter decrease		Temp.	Period	

Spawning: Optimum 11.9 (5) Range[2] 7.2-12.8(7) Dates Mar-June (5) 5,7

Hatch of normal larvae: Optimum 10.0 rising 1°/day to 20.0(6) Range[2] 6.8-19.9*(6) 6
*TL_{50} at constant temp.

Habitat:

Spawning Shallow water usually <6 feet on vegetation, sand, gravel, rocks or

Substrate nearly any substrate available 4

Larvae: Planktonic ____ Pelagic At hatch Demersal At 1" length 8

Juvenile Shallow water near shore 3

Adult Lakes and sluggish streams with open water and moderate vegetation 4

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[1] Net growth - Growth in wt. minus wt. of mortality

[2] As reported or to 50% of optimum if data permit

[3] list sources on back of page in numerical sequence.

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Yellow perch

References

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Appendix B
Tabular Summary of Numerical Criteria

Constituent	Agriculture (Irrigation)	Agriculture (Livestock)	Freshwater (Aquatic Life)	Freshwater (Wildlife)	Freshwater (Public Supply)	Marine Water (Aquatic Life)	Recreational Waters
pH	4.5-9.0	--	6.0-9.0	6.0-9.0	5.0-9.0	6.5-8.5	Acceptable - 6.5-8.3 Must be - 5.0-9.0
Alkalinity	--	--	75% natural level	30-130 mg/l	No limit*	--	--
Acidity	--	--	Addition of acids unacceptable	--	No limit	--	--
BOD	No limit	--	--	--	--	--	--
Al	5.0 mg/l 20.0 mg/l (20 yrs.)	5.0 mg/l	--	--	--	1/100 (0.01) 96-hr. LC$_{50}$ 1.5 mg/l 1/10 LD$_{50}$	--
NH_3	--	--	1/20 (0.05) LC$_{50}$ 0.02 mg/l	--	0.5 mg/l	0.4 mg/l	--
Sb	--	--	--	--	--	1/50 (0.02) 96-hr. LC$_{50}$ 0.2 mg/l	--
As	0.10 mg/l 2.0 mg/l (20 yrs.)	0.2 mg/l	--	--	0.1 mg/l	1/100 (0.01) 96-hr. LC$_{50}$ 0.05 mg/l	--
Ba	--	--	--	--	1.0 mg/l	1/20 (0.05) LD$_{50}$ 1.0 mg/l	--
Be	0.1 mg/l 0.5 mg/l (20 yrs.)	No limit	--	--	--	1/100 (0.01) 96-hr. LC$_{50}$ 1.5 mg/l	
Bi	--	--	--	--	--	No limit	--
B	0.75mg/l Sen. 1.0mg/l Semi-Tol. 2.0mg/l Tol.	5.0 mg/l	--	--	1.0 mg/l	1/10 (0.1) 96-hr. LC$_{50}$	--
Br	--	--	--	--	--	0.1 mg/l (free) 100 mg/l (ionic)	--

* "No limit", where it appears in this table, refers to constituents that were addressed but for which it was indicated that insufficient data existed for prescribing limits.

Constituent	Agriculture (Irrigation)	Agriculture (Livestock)	Freshwater (Aquatic Life)	Freshwater (Wildlife)	Freshwater (Public Supply)	Marine Water (Aquatic Life)	Recreational Waters
HCO_3	No limit	--	--	--	--	--	--
Cd	0.01 mg/1 0.05 mg/1 (20 yrs.)	50 ug/1	0.03 mg/1 hard H_2O 0.004 mg/1 soft H_2O	--	0.01 mg/1	1/100 (0.01)* 96-hr. LC_{50} 0.01 mg/1	--
Cl (free)	No limit	--	0.003 mg/1 0.05 mg/1 (30 min.)	--	--	1/10 (0.1) 96-hr. LC_{50} 0.01 mg/1	--
Cl_2 (Chloride	No limit	--	--	--	250 mg/1	--	--
Cr	0.1 mg/1 1.0 mg/1 (20 yrs.)	1.0 mg/1	0.03 mg/1	--	0.05 mg/1	1/100 (0.01) 96-hr. LC_{50} 0.1 mg/1	--
Co	0.05 mg/1 5.0 mg/1 (20 yrs.)	1.0 mg/1	--	--	--	--	--
Cu	0.20 mg/1 5.0 mg/1	0.5 mg/1	1/10 (0.1) 96-hr. LC_{50}	--	1 mg/1	1/100 (0.01) 96-hr. LC_{50} 0.05 mg/1	--
(CN)	--	--	1/20 (0.05) 96-hr. LC_{50}	--	0.2 mg/1	1/10 (0.1) 96-hr. LC_{50} 0.01 mg/1	--
F	2.0 mg/1 1.0 mg/1 (Sandy soil) 15.0 mg/1 (20 yrs.)	2.0 mg/1	--	--	--	1/10 (0.1) 96-hr. LC50 1.5 mg/1	--
H_2S	--	--	See sulfides	--	--	1/10 (0.1) 96-hr. LC_{50} 0.01 mg/1	--
Fe	5.0 mg/1 20.0 mg/1 (20 yrs.)	No limit	--	--	0.3 mg/1	0.3 mg/1	--
Pb	5.0 mg/1 10.0 mg/1	0.1 mg/1	0.03 mg/1	--	0.05 mg/1	1/50 (0.02) 96-hr. LC_{50} 0.01 LD_{50}	--
Li	2.5 mg/1 0.075 mg/1	--	--	--	--	0.01 LD_{50} 24-hr. max. 0.05 mg/1	--

* If copper or zinc is present >1 mg/1, then AF = 0.001 LC_{50}

Constituent	Agriculture (Irrigation)	Agriculture (Livestock)	Freshwater (Aquatic Life)	Freshwater (Wildlife)	Freshwater (Public Supply)	Marine Water (Aquatic Life)	Recreational Waters
Mn	0.20 mg/1 10.0 mg/1 (20 yrs.)	No limit	--	--	0.05 mg/1	1/50 (0.02) 96-hr. LC_{50} 0.01 mg/1	--
Hg Inorganic	--	1.0 ug/1	0.2 ug/1 Tot. conc. 0.05 ug/1 Avg. conc. 0.5 ug/g Body burden Conc. Tot. Hg	0.5 ug/g in fish	0.002 mg/1 Total	1/100 (0.01) 96-hr. LC_{50} 0.1 mg/1	--
Hg Organic	--	--	0.2 ug/1 Tot. conc. 0.05 ug/1 Avg. conc. 0.5 ug/g Body burden Conc. Tot. Hg	--	--	--	--
Mo	0.01 mg/1 0.05 mg/1	No limit	--	--	--	1/20 (0.05) 96-hr. LC_{50}	--
Ni	0.2 mg/1 2.0 mg/1 (20 yrs.)	--	1/50 (0.02) 96-hr. LC_{50}	--	--	1/50 (0.02) 96-hr. LC_{50} 0.1 mg/1	--
(NO_3)	No limit	100 mg/1 Combined (NO_3) & (NO_2)	--	--	10 mg/1	--	--
(NO_2)	--	10 mg/1	--	--	1 mg/1	--	--
P	--	--	--	--	No limit	1/100 (0.01) 96-hr. LC_{50} 0.1 ug/1	25 ug/1 Lakes & res. 50 ug/1 At confluence 100 ug/1 Streams
Se	0.02 mg/1	0.05 mg/1	--	--	0.01 mg/1	1/100 (0.01) 96-hr. LC_{50} 0.01 mg/1	--
Na	No limit	--	--	--	No limit	--	--
Ag	--	--	--	--	0.05 mg/1	1/20 (0.05) 96-hr. LC_{50} 5.0 ug/1	--

Constituent	Agriculture (Irrigation)	Agriculture (Livestock)	Freshwater (Aquatic Life)	Freshwater (Wildlife)	Freshwater (Public Supply)	Marine Water (Aquatic Life)	Recreational Waters
Tl	--	--	--	--	--	1/20 (0.05) 96-hr. LC_{50} 0.1 mg/l	--
U	--	--	--	--	--	1/100 (0.01) 96-hr. LC_{50} 0.5 mg/l	--
V	--	0.1 mg/l	--	--	--	1/20 (0.05) 96-hr. LC_{50}	--
Zn	--	25 mg/l	3/1000 (0.003) 96-hr. LC_{50}	--	5 mg/l	1/100 (0.01) 96-hr. LC_{50} 0.1 mg/l	--
Viruses	--	--	--	--	No limit	--	--
Micro-Organisms	--	5000 coli-forms/100 ml* 20,000/100ml**	--	2000/100 ml	10,000/100 ml	--	--
Fecal Coliforms	1000/100 ml	1000/100 ml* 4000/100 ml**	--	2000/100 ml	2000/100 ml	--	2000/100 ml avg 4000/100 ml max log mean 2n 200/100 ml <10% samples in 30-days to exceed 400/100 ml
Dissolved Solids (tot)	2000-5000 mg/l (Tolerant) 500-1000 mg/l (Sensitive)	--	Bioassays	--	No limit	--	--
Hardness	--	--	(See T.D.S.)	--	No limit	--	--
Suspended & Settleable Solids	No limit	--	80 mg/l	--	--	--	--
Temperature	No limit	--	See Text	(minimized) maintain natural pattern	not to detract from potability	2.0(3.6F)9-5 1.0(1.8F)6-8	86 F

* Average of a minimum of 2 samples per month
** Individual sample

Constituent	Agriculture (Irrigation)	Agriculture (Livestock)	Freshwater (Aquatic Life)	Freshwater (Wildlife)	Freshwater (Public Supply)	Marine Water (Aquatic Life)	Recreational Waters
Toxic Algae	--	Heavy growth of blue-green not acceptable	--	No limit	--	--	--
Botulism	--	--	--	Minimizes factors which promote disease	--	--	--
Pesticides	--	See Public Water Stnds.	1/100 (0.01) 96-hr. LC_{50} Those for which no toxicity data available. See also Tables 1&2	--	--	1/100 (0.01) 96-hr. LC_{50}	--
Dalapon	0.2 ug/l	--	--	--	Silvex 0.03	--	--
TCA	0.2 ug/l	--	--	--	2,4,5-T 0.002	--	--
2,4-D	0.1 ug/l	--	--	--	0.02 ug/l	--	--
Insecticides	No limit	--	--	DDT 1 mg/kg wet weight	Table 5 Organophosphates 0.1 mg/l	--	--
Turbidity	--	--	<10% change in C.P.	--	No limit	--	Clarity - 4 ft. Secchi
Carbon Adsorbable	--	--	--	--	0.3 mg/l CCE 1.5 CAE	--	--
Foaming Agents	--	--	--	--	0.5 mg/l (ABS)	--	--
NTA	--	--	--	--	No limit	--	--
Phenols	--	--	--	--	1 ug/l	--	--
Color	--	--	Comp. pt. not changed by >10%	--	75 platinum-cobalt units	--	--

Constituent	Agriculture (Irrigation)	Agriculture (Livestock)	Freshwater (Aquatic Life)	Freshwater (Wildlife)	Freshwater (Public Supply)	Marine Water (Aquatic Life)	Recreational Waters
Radio-activity	See Federal Drinking Water Standards	See Federal Drinking Water Standards	See Federal Drinking Water Standards	--	See Federal Drinking Water Standards	See Federal Drinking Water Standards	--
Salinity	--	3000 mg soluble salts/1	--	No rapid fluctuation	--	--	--
D.O.	--	--	See Table Section V	--	No limit saturation preferred	6.0 mg/1	--
Sulfate	--	--	--	--	250 mg/1	--	--
Sulfides	--	--	0.002 mg/1	--	--	--	--
Detergents	--	--	1/20 (0.05)(LAS) 96-hr. LC$_{50}$ 0.2 mg/1 max.	--	--	--	--
Oils	--	--	No visible oil 1/20 (0.05) 96-hr. LD$_{50}$ Hexane extractable sediments 1000 mg/kg	No visible floating oils	--	No film or odor No tainting of fish No onshore oil deposit	--
Phthalate Esters	--	--	0.3 ug/1	--	No limit	--	--
PCB's	--	--	0.002 ug/1 (in water) 0.5 ug/g (in tissue)	No increase	No limit	--	--
Tainting Substances	--	--	Tables 3&4	--	--	--	--
Odor	--	--	--	--	Free	--	--
Light	--	--	--	<10% change in C.P.	--	--	--

Appendix C

Glossary

absorption penetration of one substance into the body of another.

acclimation the process of adjusting to change, e.g., temperature, in an environment.

acute involving a stimulus severe enough to bring about a response speedily, usually within four days.

adsorption the taking up of one substance at the surface of another.

advanced (tertiary) treatment any wastewater treatment process other than conventional physical settling (primary) and biological treatment (secondary).

aerobic the condition associated with the presence of free oxygen in an environment.

aerobe an organism that can live and grow only in the presence of free ocygen.

alluvial transported and deposited by running water.

anadromous fish fish that typically inhabit seas or lakes but ascend streams at more or less regular intervals to spawn; e.g., salmon, steelhead, or American shad.

anaerobic the condition associated with the lack of free oxygen in an environment.

anaerobe an organism for whose life processes a complete or nearly complete absence of oxygen is essential.

anoxic depleted of free oxygen; anaerobic.

antagonistic causing reduction of toxicity of another chemical, interactions of organisms growing in close association, to the detriment of at least one of them.

application factor a factor applied to a short-term or acute toxicity test to estimate a concentration of waste that would be safe in a receiving water.

assimilation the transformation and incorporation of substances (e.g., nutrients) by organism or ecosystem.

benthos aquatic bottom-dwelling organisms including: (1) sessile animals, such as the sponges, barnacles, mussels, oysters, some worms, and many attached algae; (2) creeping forms, such as insects, snails, and certain clams; and (3) burrowing forms which include most clams and worms.

bioacummulation uptake and retention of environmental substances by an organism from its environment, as opposed to uptake from its food.

bioassay a determination of the concentration or dose of a given material necessary to affect a test organism under stated conditions.

biological (secondary treatment) wastewater treatment by controlled biological processes, such as trickling filters or activated sludge.

biomass the living weight of a plant or animal population, usually expressed on a unit area basis.

biotic index a numerical index using various aquatic organisms to determine their degree of tolerance to differing water conditions.

biotoxin toxin produced by a living organism (e.g., biotoxin which causes paralytic shellfish poisoning is produced by certain species of dinoflagellate algae.

bloom an unusually large number of organisms per unit of water, usually algae, made up of one or a few species.

body burden the total amount of a substance present in the body tissues and fluids of an organism.

buffer capacity the ability of a solution to maintain its pH when stressed chemically.

carrying capacity the maximum biomass that a system is capable of supporting continuously; the number of user-use periods that a recreation resource can provide in a given time span without appreciable biological or physical deterioration of that resource, or without appreciable impairment of the recreation experience for the majority of the users.

catadromous fish fishes that feed and grow in fresh water but return to the sea to spawn, e.g., the American eel.

chelate to combine with a metal ion and hold it in solution preventing it from forming an insoluble salt.

chemotaxis orientation or movement of a living organism in response to a chemical gradient.

chronic involving a stimulus that lingers or continues for a long period of time, often one-tenth of the life span or more.

climax community the stage of ecological development at which a community becomes stable, self-perpetuating, and at equilibrium with the environment.

coagulation a water treatment process in which chemicals are added to combine with or trap suspended and colloidal particles to form rapidly settling aggregates.

coliform bacteria a genera of gram-negative peritrichously flagellated or immotile, rod-shaped bacteria with the physiological ability to use either aerobic respiration or the fermentation of sugars as a source of energy; in a restricted sense the group includes *Escherichia* and *Aerobacter*, but in the broader coverage this Report also includes the genera, *Erwinia*, *Salmonella*, *Shigela*, *Serratia*, *Proteus*, and *Paseurella*, usually of fecal origin.

colloid very small particles (10 angstroms to 1 micron) which tend to remain suspended and dispersed in liquids.

conservative pollutant a pollutant that is relatively persistant and resistant to degradation, such as PCB and most chlorinated hydrocarbon insecticides.

cumulative brought about or increased in strength by successive additions.

demersal living or hatching on the bottom, as fish eggs that sink to the bottom.

detritus unconsolidated sediments comprised of both inorganic and dead and decaying organic material.

diurnal occurring once a day, i.e., with a variation period of 1 day; occurring in the daytime or during a day.

diversity the abundance in numbers of species in a specified location.

dredge spoils the material removed from the bottom during dredging operations.

dystrophi dystrophic brownwater lakes and streams usually with a low lime content and high organic content; often lacking in nutrients.

enteric of or originating in the intestinal tract.

epilimnion the surface waters in a thermally stratified body of water; these waters are characteristically well mixed.

epiphytic living on the surface of other plants.

euphotic zone the lighted region that extends vertically from the water surface to the level at which photosynthesis fails to occur because of ineffective light penetration.

eutrophication the addition of nutrients to bodies of water and the effects of such nutrients on aquatic ecosystems.

evapotranspiration the combined loss of water from a given area during a specified period of time by evaporation from the soil or water surface and by transpiration from plants.

exchange capacity the total ionic charge of the adsorption complex active in the adsorption of ions.

external treatment passage of water through equipment such as a filter or water softener to meet desired quality requirements prior to point of use.

finfish that portion of the aquatic community made up of the true fishes as opposed to invertebrate shellfish.

flocculation the process by which suspended colloidal or very fine particles are assembeld into larger masses or floccules which eventually settle out of suspension; the stirring of water after coagulant chemicals have been added to promote the formation of particles that will settle (Section II).

food chain the transfer of food energy from plants or organic detritus through a series of organisms, usually four or five, consuming and being consumed.

food web the interlocking pattern formed by a series of interconnecting food chains.

free residual chlorination chlorination that maintains the presence of hypochlorous acid (HOCl) or hypochlorite ion (OCl^-) in water.

fry the stage in the life of a fish between the hatching of the egg and the absorption of the yolk sac.

groundwood the raw material produced from both logs and chips, used mainly in the maufacture of newsprint, toweling, tissue, wallpaper, and coated specialty papers.

half-life the period of time in which a substance loses half of its active characteristics (used especially in radiological work); the time required to reduce the concentration of material by half.

hydrophytic growing in or in close proximity to water; e.g., aquatic algae and emergent aquatic vascular plants.

internal treatment treating water by addition of chemicals to meet desired quality requirements at point of use or within a process.

kraft process producing pulp from wood chips in the manufacture of paper products; involves cooling the chips in a strong solution of caustic soda and sodium sulfide.

labile unstable and likely to change under certain influences.

LC50 see median lethal concentration.

LD50 see median lethal dose.

lentic or lenitic environment standing water and its various intergrades; e.g., lakes, ponds, and swamps.

lethal involving a stimulus or effect causing death directly.

life cycle the series of life stages in the form and mode of life of an organism, i.e., between successive recurrences of a certain primary stage such as the spore, fertilized egg, seed, or resting cell.

limnetic zone the open-water region of a lake, supporting plankton and fish as the principal plants and animals.

lipophilic having an affinity for fats or other lipids.

littoral zone the shoreward or coastal region of a body of water.

lotic environment running waters, such as streams or rivers.

macronutrient a chemical element necessary in large amounts, usually greater than 1 mg/l, for the growth and development of plants.

macrophyte the larger aquatic plants, as distinct from the microscopic plants, including aquatic mosses, liverworts and larger algae as well as vascular plants; no precise toxonomic meaning; generally used synonymously with aquatic vascular plants in this Report.

make-up water water added to boiler, cooling tower, or other system to maintain the volume of water required.

marl an earthy, unconsolidated deposit formed in freshwater lakes, consisting chiefly of calcium carbonate mixed with clay or other impurities in varying proportions.

median lethal concentration (LC50) the concentration of a test material that causes death to 50 percent of a population within a given time period.

median tolerance limit (TL50) the concentration of a test material in a suitable diluent (experimental water) at which just 50 percent of the test animals are able to survive for a specified period of exposure.

mesotrophic having a moderate nutrient load resulting in moderate productivity.

metabolites products of metabolic processes.

methylation combination with the methyl radical (CH).

mho a unit of conductance reciprocal to the ohm.

micelle an aggregation or cluster of molecules, ions, or minute submicroscopic particles.

micronutrient chemical element necessary in only small amounts for growth and development; also known as trace elements.

mouse unit the amount of paralytic shellfish poison that will produce a mean death time of 15 minutes when administered intraperitoneally to male mice of a specific strain weighing between 18 and 20 grams.

necrosis the death of cellular material within the body of an organism.

nephrosclerotic a hardening of the tissues of the kidney.

nitrilotriacetate (NTA) the salt of nitrilotriacetic acid; has the ability to complex metal ions, and has been proposed as a builder for detergents.

nonconservative pollutant a pollutant that is quickly degraded and lacks persistence, such as most organophosphate insecticides.

nonfouling a property of cooling water that allows it to flow over steam condenser surfaces without accumulation of impediments.

nonpolar a chemical term for any molecule or liquid that has a reasonable degree of electrical symmetry such that there is little or no separation of charge; e.g., benzene, carbon tetrachloride, and the lower paraffin hydrocarbons.

nutrients any of a group of organic or inorganic chemicals that tend to increase the productivity of the primary food chain organisms.

oligotrophic   lakes having a small supply of nutrients and thus supporting little organic production.

organoleptic   pertaining to or perceived by a sensory organ.

parr   a young fish, usually a salmonid, between the larval stage and time it begins migration to the sea.

partition coefficient   the ratio of the molecular concentration of substance in two solvents.

pCi - picocurie   a measure of radioactivity equivalent to 3.70 x 10^{-2} atoms disintegrating per minute.

pelagic   occuring or living in the open ocean.

periphyton   associated aquatic plants attached or clinging to stems and leaves of rooted plants or other surfaces projecting above the bottom of a water body.

pesticides   any substance used to kill plants, insects, algae, fungi, and other organisms; includes herbicides, insecticides, algalcides, fungicides, and other substances.

plankton   plants (phytoplankton) and animals (zooplankton) floating in aquatic systems such as rivers, ponds, lakes, and seas.

point of supply   the location at which water is obtained from a specific source.

point of use   the location at which water is actually used in a process or incorporated into a product.

process water   water that comes in contact with an end product or with materials incorporated in an end product.

productivity   the rate of storage of organic matter in tissue by organisms including that used by organisms in maintaining themselves.

pynocline   a layer of water that exhibits rapid changes in density, analogous to thermocline.

psychrophilic   thriving at relatively low temperatures, usually at or below 15°C.

recharge to add water to the zone of saturation, as in recharge of an aquifer; the term may also be applied to the water added.

refractory resisting ordinary treatment and difficult to degrade.

rip-rapping covering stream banks and dam faces with rock or other material to prevent erosion from water contact.

safety factor a numerical value applied to short-term data from other organisms in order to approximate the concentration of a substance that will not harm or impair the organism being considered.

secchi disc a device to measure visibility depths in water.

secondary (biological) treatment see biological treatment

sessile organism motionless organisms that reside in a fixed state, attached or unattached to a substrate.

sestio particles between 0.0002 and 1 mm including suspended inorganic and organic particles as well as plankton and bacteria.

shellfish a group of mollusks usually enclosed in a self-secreted shell; includes oysters and clams.

shoal water shallow water.

sludge a solid waste fraction precipitated by a water treatment process.

smolt a young fish, usually a salmonid, as it begins and during the time it makes its seaward migration.

sorption a general term for the processes of absorption or adsorption.

species diversity a number which relates the density of organisms of each type present in habitat.

standing crop biomass the total weight of organisms present at any one time.

stratification the phenomenon occurring when a body of water becomes divided into distinguishable layers.

subacute involving a stimulus not severe enough to bring about a response speedily.

sublethal involving a stimulus below the level that causes death.

sublittoral zone the part of the shore from the lowest water level to the lower boundary of aquatic plant growth.

succession the orderly process of community change in which a sequence of communities replaces one another in a given area until a climax community is reached.

sullage waste materials or refuse; sewage.

superchlorination chlorination wherein the doses are large enough to complete all chlorination reactions and to produce a free chlorine residual so large as to require dechlorination.

surfactant surface active agent, usually refers to components of detergents.

synergistic interactions of two or more substances or organisms producing a result that **neither was capable of** independently.

tailwater water, in a river, or canal, immediately downstream from a structure; in irrigation, the water that reaches the lower end of a field.

teart a disease of cattle caused by excessive molybdenum intake characterized by profuse scouring, loss of pigmentation of the hair, and bone defects.

teratogen a substance causing birth defects.

teritiary (advanced) treatment see advanced treatment.

thermocline a layer in a thermally stratified body of water in which the temperature changes rapidly relative to the remainder of the body.

TLm see median tolerance limit.

trophic accumulation passing of a substance through a food chain such that each organism retains all or a portion of the amount in its food and eventually acquires a higher concentration in its flesh than in the food.

trophic level organisms whose food is obtained from primary producers or organic detritus by the same number of intermediate steps.

true color the color of water resulting from substances which are totally in solution. Not to be mistaken for apparent color which may result from colloidal or suspended matter.

APPENDIX D

CONVERSION TABLES

Units	Multiplied By	Equal
ACRES	4.047×10^{-1}	HECTARES
	4.356×10^{4}	SQUARE FEET
	4.047×10^{3}	SQUARE METERS
	1.562×10^{-3}	SQUARE MILES
	4.840×10^{3}	SQUARE YARDS
ANGSTROM UNITS	1×10^{-8}	CENTIMETERS
	3.937×10^{-9}	INCHES
BARRELS (Oil)	42	GALLONS (Oil)
	1.390×10^{2}	LITERS
BRITISH THERMAL UNITS	7.776×10^{2}	FOOT POUNDS
	3.927×10^{-4}	HORSE-POWER HOURS
	0.252	KILOGRAM CALORIES
	2.929×10^{-4}	KILOWATT HOURS
CENTIMETERS	3.937×10^{-1}	INCHES
DEGREES CENTIGRADE	$(^{\circ}C \times \underline{9}) + 32$	FAHRENHEIT DEGREES
DEGREES FAHRENHEIT	$(^{\circ}F - 32)\ 5/9$	CENTIGRADE DEGREES

Units	Multiplied By	Equal
FEET	12	INCHES
	1.646×10^{-4}	MILES (Nautical)
	1.894×10^{-4}	MILES (Statute)
	0.305	METERS
	1/3	YARDS
GALLONS	3.069	ACRES FEET
	3.785×10^{3}	CUBIC CENTIMETERS
	0.134	CUBIC FEET
	2.31×10^{2}	CUBIC INCHES
	3.785×10^{-3}	CUBIC METERS
	4.951×10^{-3}	CUBIC YARDS
	3.785	LITERS
	8	PINTS (Liquid)
GALLONS	4	QUARTS (Liquid)
(Imperial)	1.201	U.S. GALLONS
(U.S.)	0.833	IMPERIAL GALLONS
(Water)	8.345	POUNDS (Water: 39.2°F)
GALLONS/DAY	5.570×10^{-3}	CUBIC FEET/HOUR
	3.785	LITERS/DAY
GALLONS/MINUTE	8.021	CUBIC FEET/HOUR
	2.228×10^{-3}	CUBIC FEET/SECOND
	6.308×10^{-2}	LITERS/SECOND

Units	Multiplied By	Equal
(Water)	6.009	TONS (Water:39.2 F)/DAY
GALLONS/SQUARE FOOT/MINUTE	40.74	LITERS/SQUARE METER/ MINUTE
GALLONS/SQUARE MILE	1.461	LITERS/SQUARE KILOMETER
GALLONS/TON (Short)	4.173	LITERS/TON (Metric)
GRAMS	3.527×10^{-2}	OUNCES
	2.205×10^{-3}	POUNDS
GRAMS/LITER	58.41	GRAINS/GALLON
	10^{3}	PARTS PER MILLION
(assumes density of 1 gram/milliliter)		
	8.345×10^{-3}	POUNDS/GALLON
	6.243×10^{-2}	POUNDS/CUBIC FOOT
GRAMS/CUBIC METER	0.437	GRAINS/CUBIC FOOT
INCHES	2.54	CENTIMETERS
KILOGRAMS	2.205	POUNDS
	1.102×10^{-3}	TONS (Short)
	9.842×10^{-4}	TONS (Long)
KILOMETERS	3.281×10^{3}	FEET
	3.937×10^{4}	INCHES
	0.621	MILES (Statute)
	0.540	MILES (Nautical)
	1.094×10^{3}	YARDS
LITERS	1.000028×10^{3}	CUBIC CENTIMETERS

Units	Multiplied By	Equal
	3.532×10^{-2}	CUBIC FEET
	6.103	CUBIC INCHES
	1.000028×10^{-3}	CUBIC METERS
	1.308×10^{-3}	CUBIC YARDS
	0.277	GALLONS
LITERS/SQUARE KILOMETER	0.588	GALLONS/SQUARE MILE
METERS	3.281	FEET
	39.37	INCHES
	5.400×10^{-4}	MILES (Nautical)
	6.214×10^{-4}	MILES (Statute)
	1.094	YARDS
MICRONS	10^{4}	ANGSTROM UNITS
	10^{-4}	CENTIMETERS
	3.281×10^{-6}	FEET
	3.937×10^{-5}	INCHES
	10^{-6}	METERS
	10^{-3}	MILLIMETERS
MILES (Nautical)	6.076×10^{3}	FEET
	1.852	KILOMETERS
	1.852×10^{3}	METERS
	1.151	MILES (Statute)
	2.027×10^{3}	YARDS

Units	Multiplied By	Equal
MILES (Statute)	5.280×10^{3}	FEET
	6.336×10^{4}	INCHES
	1.609	KILOMETERS
	1.609×10^{3}	METERS
	0.869	MILES (Nautical)
	1.760×10^{3}	YARDS
MILIGRAMS	3.527×10^{-5}	OUNCES
	2.205×10^{-6}	POUNDS
MILLILITERS	1.000028	CUBIC CENTIMETERS
	6.102×10^{-2}	CUBIC INCHES
	3.381×10^{-2}	OUNCES (U.S.)
MILLIMETERS	3.281×10^{-3}	FEET
	3.937×10^{-2}	INCHES
	10^{-3}	METERS
	10^{3}	MICRONS
	1.094×10^{-3}	YARDS
MILLION GALLONS/DAY	1.547	CUBIC FEET/SECOND
	0.028	CUBIC METERS/SECOND
	28.32	LITERS/SECOND
POUNDS	0.454	KILOGRAMS
	16	OUNCES
	4.464×10^{-4}	TONS (Long)

Units	Multiplied By	Equal
	4.536×10^{-4}	TONS (Metric)
	5.0×10^{-4}	TONS (Short)
POUNDS/ACRE	1.122	KILOGRAMS/HECTARE
POUNDS/GALLON	0.120	GRAMS/CUBIC CENTIMETER
	7.480	POUNDS/CUBIC FOOT
POUNDS/SQUARE INCH	6.805×10^{-3}	ATOMOSPHERES
	5.171	CENTIMETERS OF MECURY (0°C)
	70.31	CENTIMETERS OF WATER (4°C)
	6.895×10^{4}	DYNES/SQUARE CENTIMETER
	70.31	GRAMS/SQUARE CENTIMETER
	27.68	INCHES OF WATER (39.2°F)
	2.036	INCHES OF MERCURY (32°F)
	7.031×10^{2}	KILOGRAMS/SQUARE METER
	1.440×10^{2}	POUNDS/SQUARE FOOT
SQUARE FEET	2.296×10^{-5}	ACRES
	1.44×10^{2}	SQUARE INCHES
	9.290×10^{-2}	SQUARE METERS
	3.587×10^{-8}	SQUARE MILES
	1/9	SQUARE YARDS

Units	Multiplied By	Equal
SQUARE METERS	2.471×10^{-4}	ACRES
	10^{-4}	HECTARES
	10^{4}	SQUARE CENTIMETERS
	10.76	SQUARE FEET
	1.550×10^{3}	SQUARE INCHES
SQUARE METERS	3.861×10^{-7}	SQUARE MILES
	1.196	SQUARE YARDS
SQUARE MILES	6.40×10^{2}	ACRES
	2.590×10^{2}	HECTARES
	2.788×10^{7}	SQUARE FEET
	2.590	SQUARE KILOMETERS
	3.098×10^{6}	SQUARE YARDS
TONS (Metric)	10^{3}	KILOGRAMS
	3.527×10^{4}	OUNCES
	2.205×10^{3}	POUNDS
	0.984	TONS (Long)
	1.102	TONS (Short)
TONS (Short)	8.897×10^{8}	DYNES
	9.072×10^{2}	KILOGRAMS
	3.2×10^{4}	OUNCES
	2×10^{3}	POUNDS
	0.893	TONS (Long)

Units	Multiplied By	Equal
	0.907	TONS (Metric)
WATTS	3.414	BTU/HOUR
	44.25	FOOT-POUNDS/MINUTE
	1.341×10^{-3}	HORSE POWER
	1.434×10^{-2}	KILOGRAM-CALORIES/ MINUTE
YARDS	91.44	CENTIMETERS
	3	FEET
	36	INCHES
	0.914	METERS
	4.934×10^{-4}	MILES (Nautical)
	5.682×10^{-4}	MILES (Statute)

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